Age-Related Differences in Thematic and Taxonomic Semantic Processing

by

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Over the lifespan, cognitive abilities are subject to change and decline. While there is a general slowing of cognitive processing with age (Mather, 2010), certain functions are disproportionately impacted by aging over others. Language function follows the variable pattern of age-related change noted above. Certain language functions are well-maintained throughout the lifespan, while others are not (Shafto & Tyler, 2014). The present study was motivated by the cognitive and linguistic changes that accompany aging to investigate differences in lexical access between younger and older adults. Specifically, the current study investigated differences in semantic (i.e., meaning-based) similarly using eye-gaze measures. Two types of semantic relationships were investigated: taxonomic (i.e., shared features or categories) and thematic (i.e., co-occurrence in scenes) relationships. Following the Regression Hypothesis, we predicted specific interference from thematic competitors for older adults based on an increased preference towards thematic thinking across the lifespan (Belacchi & Artuso, 2018; Maintenant et al., 2011; Smiley & Brown, 1979). We also expected that older adults may experience a general increase in semantic competition, for both taxonomic and thematic semantic competitors, consistent with the Inhibitory Deficit Hypothesis (Hasher et al., 1999). Nine younger and one older adult participated in the study. Data was collected using the Visual World Paradigm (VWP). Participants viewed four images on a screen while hearing a word and were instructed to select the image that corresponded to the spoken word presented. Participants were presented with an image of the target word, a phonological competitor, a semantic competitor (either thematically or taxonomically related to the target word), and an unrelated distractor. Cumulative gazes to each type of competitor were used as a dependent measure. Results showed that there were no significant difference in gazes to either taxonomic or thematic semantic competitors. Descriptive statistics for the older adult revealed more gazes to the thematic than the taxonomic semantic competitor. These results are consistent in part with the Regression Hypothesis but are inconsistent with the Inhibitory Deficit Hypothesis. This study provides preliminary findings regarding age-related changes in semantic processing; however, future work should expand upon and validate the findings reported here.

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Preface

I have been very fortunate to work with a supportive and knowledgeable team to complete this project. I want to thank my mentor, Dr. Michael Walsh Dickey, for his consistent encouragement and assistance throughout this project. I am also endlessly grateful to my committee members for providing insight, advice, and support along the way. Finally, I am grateful for members of the Language and Brain Lab, Anna Rosenberg, Kaitlin Zarbis, and Emily Goldberg for working with and advising me since I began working on my thesis.

1.0 Introduction

1.1 Aging Introduction

The normal aging process leads to physiological changes in the brain that impact structure and function. Gray and white matter are subject to age-related reductions; however, the rate and timing with which regional gray and white matter volumes deteriorate is inequivalent among brain regions (Shafto & Tyler, 2014). Based on these discordant variations in gray and white matter reduction, it is expected that certain cognitive functions remain relatively intact across the lifespan, while others are more vulnerable to decline and change.

While there is a general slowing of cognitive processing with age (Mather, 2010), certain functions are indeed disproportionately impacted by aging over others. Functions like working memory, demonstrate age-related decline (Shafto & Tyler, 2014), while those like semantic memory remain relatively stable across the lifespan (Mather, 2010). It is also important to note that the degree of brain matter reduction is not directly correlated to the amount of functional impairment observed (Shafto & Tyler, 2014), further complicating changes observed across the lifespan. Language processing recruits cognitive processes in addition to language-specific processes, and involves various intersecting networks (Shafto & Tyler, 2014), making it an interesting avenue to explore in the context of age-related changes in function.

Language processing follows the variable pattern of age-related change described above. Language comprehension and automatic lexical access are preserved with older age, while word production is subject to impairment (Shafto & Tyler, 2014). Comprehension is thought to be a relatively stable skill because it is underpinned by abilities that strengthen with increasing age, including language use (Ben-David et al., 2015), crystalized intelligence (Horn & Catell, 1967), and semantic memory (Mather, 2010).

1.2 Language Processing Overview

In understanding the age-related changes and preservation associated with language, it is important to begin with a discussion of how language is processed. Three terms, lexicon, lexical item, and lexical access are relevant to the present discussion. The lexicon refers to the words that one can use and/or understand. A lexical item is a word or phrase within the lexicon that carries meaning. Lexical access is the process of selecting a specific lexical item from the lexicon. In addition to these definitions, an understanding of the terms phonology and semantics is important. Phonology refers to the sound system of language, while semantics is concerned with the meaning of language.

Lexical access is imperative for functional language comprehension and involves the processes of activation and selection of lexical items (Yee et al., 2008). Auditory lexical access follows a bottom-up processing pattern that begins with phoneme recognition from the acoustic signal and terminates with semantic processing of the encountered lexical items (Taylor & Burke, 2002). However, during this process, various lexical items are activated, resulting in competition among lexical candidates (Taylor & Burke, 2002).

The acoustic signal is first refined and transformed into a phonetic-phonological representation (e.g., the acoustic information associated with /s/ becomes converted into the mental representation for the phoneme /s/; Yee et al., 2008). After this process, the phonetic-phonological representation connects to the lexicon, where a plausible lexical item is selected from various candidates (Yee et al., 2008). It is helpful to imagine this as a mapping process; waveforms are mapped onto phonemes that are then mapped onto lexical items. Once a lexical item has been selected, it contacts the lexical-semantic network associated with it, activating the meaning of the lexical item (Yee et al., 2008).

The figure below demonstrates this process for the lexical item ‘ball.’ Beginning at the bottom of the figure, the phonemes /b/, /ɔ/, /l/ are first encountered. Next, these phonemes are mapped onto the lexical item ‘ball.’ The lexical item is connected to two semantic networks, one depicting a formal dance and the other depicting a round toy.

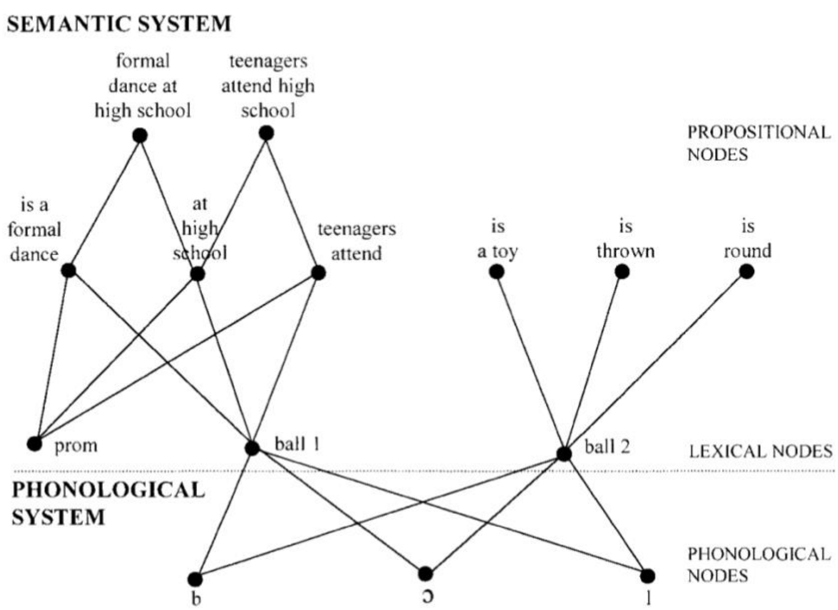

Figure 1. Processing levels involved in lexical access for ‘ball.’

Source: Taylor & Burke (2002)

While this proposed sequence of events is thought to occur during auditory lexical access, it is unlikely that lexical access follows a completely linear pattern due to the interactions of the interrelated neural system that underpin this process (Shafto & Tyler, 2014). These interactions result in the spread of activation of information within and between levels (Yee et al., 2008) activating lexical items that share information. As a result, multiple activated candidates compete for selection until the proper lexical item is chosen (Allopenna et al., 1998, Marslen-Wilson, 1987).

Spreading activation within a level (e.g., within the level of the lexicon) and its implications will further be discussed in this section. During this process, multiple lexical items that fit the properties of the encountered acoustic signal are activated while it is being processed (Zhuang et al., 2016). These properties may be based on shared phonological features. For example, hearing the beginning part of the word ‘lion’ may activate ‘lime,’ or ‘light’ because these words share similar onsets. Additionally, shared meaning, or semantic similarity, may drive activation. Encountering ‘grapefruit’ may activate ‘orange,’ or ‘lemon,’ because these items all share similar features and belong to the category of citrus fruits. It is clear that similarities in sound and meaning activate many plausible lexical candidates; however, the components of the activation and selection process are of interest to the present study. Properties of competitors, as well as cognitive abilities, like inhibition, and their change throughout the lifespan may influence the speed and accuracy with which lexical access is conducted.

In sum, lexical information must be stored, as well as retrieved, for functional language comprehension to occur. It is the activation of multiple candidates that leads to competition among items and requires selection of the proper one. Methodology that can be used to investigate activation and competition processes will be described next, followed by research related to specific types of competition and their impact on behavioral and neurological responses.

1.3 Visual World Paradigm

The Visual World Paradigm (VWP) capitalizes on the temporally sensitive relationship between auditory word presentation and eye gaze (Allopenna, Magnuson, & Tanenhaus, 1998; Cooper, 1974). When presented with objects in a visual display, it has been found that individuals will gaze at an object when they hear the corresponding word for that object, as well as objects that are related to the encountered word (Cooper, 1974). This knowledge has been used to investigate lexical access by using eye tracking technology. Experiments using the VWP are conducted by having a participant seated in front of a screen while an eye tracker is in place and they are presented with images and hear words (see example below; Huettig & Altmann, 2005). Analyzing gaze patterns across different points in time during auditory word presentation provides insight into the processing that occurs during lexical access, including activation and competition processes. Understanding the VWP will assist in the understanding of previous studies that have employed this methodology, as well as with the design and results of the current study.

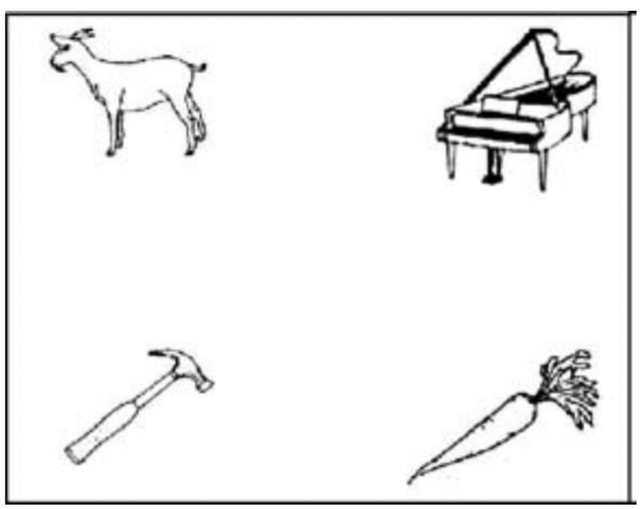

Figure 2. Example of a display in the VWP.

Source: Huettig & Altmann (2005)

1.4 Phonological and Semantic Competition

Lexical competition in experimental paradigms has been demonstrated due to both phonological and semantic similarity. Allopena et al. (1998) investigated the presence of phonological competition using the VWP. Two experiments were conducted. Experiment 1 investigated the timing of activation of phonological and rhyme competitors (i.e., words that share an onset or rhyme with a target). Experiment 2 varied the duration of the word onset using a gating task (Grosjean, 1980) and examined its effects on phonological and rhyme competition. Participants were presented with four combinations of images on a screen; a *full competitor set* consisting of a target (e.g., beaker), an onset competitor (e.g., beetle: a word whose initial phonemes overlap with the target), a rhyme competitor (e.g., speaker: a word whose final phonemes overlap with the target), and an unrelated distractor (carriage); a *cohort competitor set* containing the target, an onset competitor, and two unrelated distractors; a *rhyme competitor set* containing the target, a rhyme competitor, and two unrelated distractors; and an *unrelated set* containing the target and three unrelated distractors. In Experiment 1, participants were auditorily instructed to pick up one of the images (the target) and move it to a specified location on the screen. Eye gazes were measured beginning from the onset of the target word until the participant moved their mouse to the correct image. Results demonstrated that there were both phonological and rhyme competition effects, and that fixations on the phonological competitor occurred earlier and were greater than for rhyme competitors. Experiment 2 showed that with increasing fragments of the target word provided, participants were more likely to gaze at the target rather than the phonological competitor, while increases in gating did not activate the rhyme competitor Overall, these results demonstrate the existence of rhyme and phonological competitor effects.

Following the discussion of phonological competition effects, this section discusses available evidence regarding semantic competitor effects in similar paradigms. Huettig & Altmann (2005) used eye-tracking to investigate the effects of semantic similarity on gaze patterns. Participants were seated in front of a screen and heard a sentence containing the target word. There were three different display conditions; a *target condition* consisting of an image of the target word (e.g., trumpet) and three unrelated distractors; a *competitor condition* containing a word semantically related to the target (e.g., piano) and three unrelated distractors; and a *target and competitor condition* containing the target a semantic competitor and two unrelated distractors. The semantic competitor chosen belonged to the same category as the target, which most closely resembles a taxonomic relationship (to be discussed later). Participants did not manipulate any of the images on the screen, rather they were instructed just to look at the screen. Results revealed more fixations to the target in the target condition and more fixations to the competitor in the competitor condition. In the target and competitor condition, the target received the greatest number of fixations compared to the competitor and unrelated distractors; however, the competitor received more fixations than either unrelated distractor. These results show that activating semantic information for a target also activates information for a semantically related object.

These studies provide the foundation for the existence of phonological and semantic competition that is rooted in activation and selection processes. Knowledge that these differences exist motivate investigation of whether specific characteristics of lexical items can influence the degree of competition, such as different kinds of semantic competitors, as well as how these characteristics impact competition in different age groups.

1.5 Age-Related Differences in Lexical Access

Research has also been conducted to investigate age-related differences in lexical access using eye-tracking. Harel-Arbeli et al. (2021) used the VWP to analyze differences in semantic competition and context between younger and older adults. In this experiment, participants were presented with four images on a screen while they were asked to select the image that matched the last word in an auditorily presented sentence. There were three sentence conditions: a sentence containing predictive context corresponding to one of the images (*semantic context/no competition,* e.g., 'In the winter, better take an umbrella,' where umbrella is the only plausible option in the image display), a sentence containing predictive context corresponding to two of the images, (*semantic context/semantic competition*, e.g., 'In the winter, better take an umbrella,' where a coat and an umbrella are present in the image display), and a sentence that did not contain predictive context (*no competition*, e.g., 'On the display, there is an image of a book'). Eye gaze was compared with response accuracy and response time to analyze the differences between online and offline measures. Younger and older adults were comparable in their accuracy of selecting the correct image to complete the sentence, while older adults were slightly slower to select the image. After presentation of the target word in the semantic context/semantic competition condition, older adults were slower to gaze at the image of the target word after it was presented, indicating that they demonstrate greater semantic competitor effects than younger adults and may have more difficulty inhibiting competing information. These results also inform the sensitivity and perceptibility of lexical competition effects. While older adults appeared to exhibit greater semantic competition, this competition did not compromise accuracy.

Yee et al. (2008) also investigated semantic competition in healthy younger and older adults, as well as in individuals with Broca's and Wernicke's aphasia. Three experiments were conducted in this study using eye-tracking. The first investigated semantic competition, the second analyzed phonological competition, and the third investigated whether a semantic competitor would be activated after exposure to a phonological competitor (semantic onset competition, e.g., does the word 'hammock' activate 'nail' because of the onset similarity between 'hammock' and 'hammer'). Participants were presented with four images on a screen containing the target (e.g., hammer), a competitor (e.g., semantic: nail, phonological: hammock), and two unrelated images (e.g., vase). On each trial, participants were presented with the target word auditorily and instructed to select the image that matched the audio. In Experiment 1, healthy younger and older adults showed more gazes towards the semantically related image than an unrelated distractor. Results in Experiment 2 were similar, with both younger and older adults gazing at the phonological competitor more than the unrelated image. Experiment 3 demonstrated that younger and older controls gazed significantly more at the semantic onset competitor than at the unrelated images. Based on these data, healthy younger and older adults demonstrate competitor effects based on semantic, phonological, and phonologically-mediated semantic similarity.

Zhuang et al. (2016) combined behavioral and neuroimaging measures to investigate age-related differences between phonological and semantic competition using functional magnetic resonance imaging (fMRI). This study employed a similarity judgment task, requiring participants to choose which of two choices best matched a target. There were three conditions: a *rhyme judgment* task where participants were presented with a target word (e.g., blast), a word that rhymes with it (e.g., passed), and an unrelated distractor (e.g., toast); a *semantic similarity judgement* task consisting of the target word (e.g., shrimp), a semantically similar word (e.g., crab), and an unrelated distractor (e.g., tears); and a *perceptual similarity judgement* task consisting of three dot clusters where two are similar. Similarity judgments were collected using a button-press response while participants were in the fMRI scanner. Results showed that younger adults responded faster than older adults for all tasks, but that older adults responded more accurately during the semantic similarity task. Imaging data revealed that the semantic similarity task recruited the posterior left middle frontal gyrus more for all participants, and that older adults had greater activation in the left inferior frontal gyrus, left fusiform gyrus, and bilateral posterior cingulate than younger adults during the semantic similarity task. Further, increased activity in the left inferior frontal gyrus was associated with increased accuracy in the semantic condition for all participants. It is important to note that the inferior frontal gyrus is associated with resolving semantic competition (Schnur et al., 2009; Thompson-Schill et al., 1997). The combination of increased accuracy and increased activation of the left inferior frontal gyrus in older adults during the semantic similarity task provides support for the preservation of semantic processing across the lifespan. However, the fact that older adults recruited left inferior frontal gyrus more than their younger peers suggests that older adults may experience greater competition from overlapping semantic representations than younger adults do.

The studies discussed here demonstrate different ways in which age-related differences regarding lexical competition have been observed, as well as preservation of lexical access across the age span (Yee et al., 2008). Based on behavioral responses, older and younger adults appear similar in terms of their accuracy lexical processing (Harel-Arbeli et al., 2021), and that older adults may even perform more accurately than younger adults (Zhuang et al., 2016), but older adults appear to respond more slowly than younger adults offline (Harel-Arbeli et al., 2021; Zhuang et al., 2016). Measures of eye gaze and neural activation offer additional insight into differences in semantic lexical access for older adults. These include potential reduced inhibition, reflected by increased time to look at the target after its presentation (Harel-Arbeli et al., 2021), and increased activity in the left inferior frontal gyrus that is associated with increased task accuracy (Zhuang et al., 2016). These studies provide some insight into differences in lexical access across the lifespan, but it is important that further work be conducted to investigate more specific differences between older and younger adults.

1.6 Semantic Processing & Implications of Age

The components underpinning semantic relatedness between and among words can be separated into one of two types of semantic relationships. The first, taxonomic semantic structure, is based on shared categories or features (Mirman et al., 2017), for example a dog and a cat. These animals are both domesticated, similar in size, and have four legs. The latter, thematic semantic structure, arises from repeated pairings of entities, producing an association among them (Mirman et al., 2017), such as a dog and a leash. Although dog and leash do not share any perceptual features, a dog is frequently associated with a leash due to the two words or concepts frequently appearing together in sentences or situations. Taxonomic relationships are considered to be "more abstract and logic based," while thematic relationships are "intuitive and experience based" (Belacchi & Artuso, 2018).

Knowing that these semantic relationships are based on different types of associations, differences in processing likely exist for these two types of semantic structure. Dissociations between taxonomic and thematic relationships have been demonstrated in various studies. Studies using the VWP have uncovered differences in the timing of activation for taxonomic versus thematic competition. Thematic distractors have been shown to be gazed at earlier than taxonomic distractors (Kalénine et al., 2012), indicating that the thematic competitor was activated earlier than the taxonomic competitor, providing further evidence for the division between these two types of semantic relationships.

Both types of relations show equivalent benefit during word recall tasks, if the cues given are consistent with the relation that was studied (Ackerman, 1986). For example, if the target word ‘guitar’ were studied in a taxonomically related list (piano-trumpet-guitar), a taxonomic cue (instrument) would facilitate recall more than a thematic cue (concert). The reverse would be true if the target word were studied in a thematically related list (stage-speaker-guitar).

In a picture-word interference task, where a participant is instructed to name an image while hearing a distractor word (Mirman et al., 2017), distractors that were taxonomically related to the image were shown to inhibit picture naming, while thematic distractors facilitated picture naming in healthy adults (de Zubicaray, Hansen, & McMahon, 2013). Developmental implications of this task have been observed, as well. In children aged 7-11, only the thematic facilitation effect, but not the taxonomic inhibition effect, was found for the picture-word interference task (Brooks, Seiger-Gardner, & Sailor, 2012). These findings suggest that the thematic system develops earlier than the taxonomic system (Mirman et al., 2017). In addition, findings that older children produce more taxonomic responses in word association tasks (i.e., where the participant is presented with a word and asked to say the first word that comes to mind) than younger children also provide evidence for these differences in the development of taxonomic and thematic systems (Borghi & Caramelli, 2003; Sell, 1992). Others have provided evidence for the generally earlier acquisition of the thematic system, as well (as cited in Belacchi & Artuso, 2018).

Smiley & Brown (1979) investigated preferences for thematic and taxonomic responses based on age. This study used a match-to-sample task and tested five different groups: preschoolers, first graders, fifth graders, college-aged adults, and elderly adults. All participants were presented with an image of the target word (e.g., needle) and two related words. One of the related words was taxonomically related to the target (e.g., pin) and the other was thematically related (e.g., thread). Kindergarteners and older adults showed a preference for the thematically related image, while fifth graders and college-aged adults preferred the taxonomically related image. These results indicate the possibility of a shift in preference across the lifespan, moving from a preference for thematic relations to taxonomic relations with increasing age, and a reversal to thematic preference in older adulthood. However, the findings presented in this study are thought to emerge due to the salience of the association between the specific stimuli used in the study rather than preferences based on the type of semantic relationship (Mirman et al., 2017; Maintenant et al., 2013; Pennequin et al., 2006). Lin & Murphy (2001) used the same stimuli as the study described here and found that college-age adults provided predominantly thematic responses. Based on this task and the findings noted above, it is unclear whether there is a regression in semantic categorization, (hereafter referred to as the *Regression Hypothesis*; Maintenant et al., 2013), across the lifespan.

Belacchi & Artuso (2018) investigated age-related differences between taxonomic and thematic semantic relations on word recall in adults. Participants ranged in age from 18-85 years old that were divided into five age groups: young-adults, adults, middle-aged adults, young-old adults, and old-old adults. This study employed a complex semantic working memory task using lists of four words that were either taxonomically related, thematically related, or unrelated. Participants were instructed to recall the last word in each list and were presented with between two and six lists per trial. Results indicated that for young adults, recall was the same for words presented in taxonomic and thematic lists. Adults and middle-aged adults recalled more words when they were presented in a taxonomic list than a thematic list. Young-old adults also showed similar recall for words presented in taxonomic and thematic lists. However, for the old-old adults, words presented in a thematic list were recalled more accurately than those presented in the taxonomic lists. These results are consistent with the regression hypothesis and demonstrate a potential decline in taxonomic semantic organization and an increased reliance on thematic relations with increasing age.

Maintenant et al. (2011) investigated differences between categorical flexibility in older and younger adults. They define categorical flexibility as "the ability to manage multiple memberships of objects in electing the relevant representations as a function of a situation" (pg. 265). In this study, participants had to eliminate one of three photos in a set that did not go best with the other two, according to rules provided by the examiners. Pictures were either thematically or taxonomically related, or unrelated to one another. Sets were either nonconflicting, where there was only one clear match in the three photos (e.g., dog, elephant, piano), or conflicting, where two combinations were possible based on the semantic relation being used to create the match (e.g., dog, bone, and elephant). Participants were provided feedback as to whether the match they had created was correct, based on the rule they were supposed to be following (e.g., following taxonomic or thematic grouping). There were three phases: Phase 1 enforced one categorial relation (either thematic or taxonomic) using nonconflicting sets, Phase 2 ('maintenance') continued to enforce the same relation as Phase 1 but with conflicting sets, and Phase 3 ('switching') required participants to change to the other relation and continue to use it for the remainder of the set. All participants performed well on Phase 1, indicating that all participants were able to understand and use the specific relation required. When presented with conflicting sets in Phase 2, older adults required a larger number of trials than younger adults to reach the success criterion, potentially showing difficulty inhibiting the competing relation (consistent with the Inhibitory Deficit Hypothesis, to be discussed later). Additionally, older adults had more difficulty than younger adults in continuing to use the taxonomic relation when there was a thematic competitor present, while this effect was not present for thematic relations. In Phase 3, older adults had more difficulty switching from a thematic to a taxonomic relation than the opposite, while younger adults did not show this pattern. Overall, these results indicate more difficulty with taxonomic relationships for older adults, which is consistent with the regression hypothesis.

The evidence presented here demonstrates that there are differences between taxonomic and thematic semantic relationships that can be observed as early as childhood. General processing of taxonomic and thematic items has revealed differences in the timing of activation, as well as different effects during picture naming. Evidence regarding differences in taxonomic and thematic preference across the adult lifespan is unclear, with some work providing evidence for the Regression Hypothesis, showing a preference towards thematic thinking with older age. Further work is required to understand the pattern of semantic processing across the lifespan. Understanding the differences in taxonomic and thematic processing with increasing age can provide insight into competition effects in older adulthood, as well as relative preservation of specific semantic information. The present study is strongly motivated by this gap in knowledge to investigate whether there are differences between taxonomic and thematic processing between older and younger adults, as well as how these potential differences may influence activation and competition processes when using the VWP. Hypotheses that relate to processes required for lexical access and their impact on the expected results of this study will be discussed next.

1.7 Relevant Hypotheses

The Inhibitory Deficit Hypothesis suggests that older adults have a reduced ability to inhibit distracting information compared to younger adults (Hasher et al., 1991). This decreased inhibition has been demonstrated in visual and auditory tasks (as cited in Harel-Arbeli et al., 2021) and involves the inability to inhibit internal and external distractors (Taylor & Burke, 2002). In the realm of language comprehension, various distractors may be present during the presentation of spoken language. The reduced ability to inhibit internal information may increase the spread of information activation, such as semantically related information (as cited in Taylor & Burke, 2002). As such, a larger number of lexical items, for example, may be activated when an older adult encounters a word compared to when a younger adult does, which may increase the demands placed on the selection process.

Further, it is unclear whether the inhibition deficits occur during the process of lexical activation, that of inhibiting activated competitors, or both (Harel-Arbeli et al., 2021). As previously discussed, adequate lexical access requires both activation and selection processes. Reductions in the ability to perform any step of this process may compromise lexical access, or timely lexical access. It is also important to note that the Inhibitory Deficit Hypothesis does not implicate increased interference towards a specific form of lexical processing over another. In other words, inhibition deficits proposed by this hypothesis are very general, indicating that older adults may demonstrate a generally reduced ability to inhibit any type of distracting or irrelevant information. These difficulties may manifest as an overall increased semantic competitor effect, rather than an asymmetric effect of competition for different types of competitors, such as taxonomic versus thematic semantic competitors.

In contrast to the Inhibitory Deficit Hypothesis, age-related differences specifically uncovered between taxonomic and thematic semantic items (as cited in Mirman et al., 2017; Smiley & Brown, 1979; Belacchi & Artuso, 2018; Maintenant, Blaye, & Paour, 2011) may result in asymmetrical competition effects. Following the regression hypothesis, thematically related items may increase the competitor effect for these images because these relationships are more salient and preferred by older adults, making them more difficult to inhibit. Taxonomic items may similarly affect younger adults, who may have a preference for this kind of semantic relationship.

An interaction between both hypotheses proposed above is also plausible in the present study. It is possible that older adults may have a generally decreased ability to employ inhibition, while also facing increased competitor effects from thematic competitors. These results would suggest that older adults may have difficulty inhibiting irrelevant information, and that this reduced inhibition can be exacerbated by specific forms of stimuli.

2.0 Current Study

2.1 Research Questions & Hypotheses

The current study intended to use eye-tracking methodology and the VWP to investigate the effects of healthy aging on taxonomic and thematic competition. Previous studies have demonstrated that semantic competition can be observed using the VWP (Huettig & Altmann, 2005; Harel-Arbeli et al., 2021; Yee et al., 2008; Zhuang et al., 2016) and differences in taxonomic and thematic distractors have been shown using this paradigm, as well (Kalénine et al., 2012). Based on this background, the VWP is an adequate method that can be employed to investigate this topic. We proposed the following research questions in this study:

1. What, if any, age-related differences exist between taxonomic and thematic semantic processing?
2. If any age-related differences are observed, are they best explained by the inhibitory deficit hypothesis, the regression hypothesis, or a combination of the two?

Eye gaze was used as a dependent measure to infer the amount of competition posed by each type of semantic competitor. The amount of time gazed at each competitor was used to demonstrate competition for that specific item.

Building upon previous research and knowledge of the healthy aging process, we hypothesized three potential patterns of findings:

1. Consistent with the Inhibitory Deficit Hypothesis, we predicted that older adults would show a greater number of gazes to both types of semantic competitors than

younger adults due to a reduced ability to inhibit either form of competition, taxonomic or thematic.

2. Based on the Regression Hypothesis, we predicted that older adults would show significantly more gazes to the thematic than the taxonomic competitor compared to younger adults because of previous findings that older adults have a preference for thematic thinking, making these types of competitors more difficult to inhibit. A similar pattern would be expected for younger adults and taxonomically related items.
3. Combining both hypotheses, we predicted that older adults would show a generally greater competition effect than younger adults, evidenced by a greater number of gazes to both types of competitors, in addition to an asymmetric competitor effect for older adults, with more gazes to the thematic than the taxonomic competitor.

2.2 Methods

2.2.1 Participants

Nine healthy younger (mean age: 23.33, 8 female, 1 male) and one older (age 62, female) adults in the Pittsburgh, Pennsylvania area were recruited for the present study. All participants were recruited through word of mouth. Both younger and older participants were required to be free of neurological, cognitive, neuropsychiatric, or language conditions. Participants were required to have normal or corrected hearing and vision, be native English speakers, and be able to view a screen for an extended period of time. Participants voluntarily participated in the study with knowledge of the absence of compensation or reward for participation.

A priori power analysis was carried out in G*power (Faul et al., 2009) to determine the proposed sample size. Values for the power analysis were based upon Harel-Arbeli (2021) which investigated aging effects on semantic competition using the VWP. As described above, they found an interaction of age (older vs. younger) and fixations (target vs. distractor) following presentation of the target word, with older adults demonstrating greater competition effects from the distractor. The effect size for the interaction in this study was small to medium (partial eta squared = .117, Cohen's f = .364). The present study assumed a conservative estimate of the size of this interaction (25% of Harel-Arbeli's: partial eta = .029, Cohen's f = .174) and a medium correlation between repeated measures (.5). Based on the power analysis, it is suggested that 22 participants in each group will be needed to obtain .95 power. We planned to recruit 25 participants per group to account for an expected attrition rate of about 10%. Given constraints related to finances and timing, the desired sample size was not obtained. Data analysis modifications and limitations related to the sample size obtained will be discussed.

2.2.2 Stimuli & Apparatus

Sixty trials were presented to participants. Each trial contained the following images in a 4x4 grid: the target word (e.g., lemon), a semantic competitor (e.g., taxonomic: grapefruit, thematic: knife), a phonological competitor (e.g., lion), and an unrelated image (e.g., sand). The target word was presented over a loudspeaker while participants gazed at the images. The locations of the four images in the grid were pseudorandomized using a Latin Square design to ensure that gazes to any of the four images were not due to the configuration of the images on the screen.

A fixation cross preceded all trials to direct participants' gazes towards the center of the screen. By having participants gaze at the center of the screen, we avoided random gazes to any of the images in the array at the beginning of each trial. The fixation cross was presented for 200 ms. The visual display containing the array of images then appeared, and the target word was presented over the loudspeaker 1000 ms after the visual stimuli appeared. Participants were instructed to select the image that matched the word they heard with a mouse click.

Images presented to participants were taken from publicly available image sources (e.g., Google searches, CC BY license) trimmed to 240 by 360 pixels. All target stimuli were drawn from a battery of 325 picturable objects. All object images were normed with an independent sample of neurotypical adults between 21 and 80 years old. These adults were asked to name the images. All images were found to have name agreement in excess of 85%. 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 a male native speaker of American English and normalized and measured for duration in Audacity. 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).

Semantic distractor images were coded by two independent raters to determine if they were taxonomically or thematically related to the target image. The two raters compared their coding and incongruent ratings were discussed until agreement was reached. The stimuli were then sent to a third independent rater who also coded the stimuli. Those ratings were then compared to the previously agreed-upon ratings and discrepancies were discussed once again. Following all rating procedures, all semantic distractor image ratings reached 100% agreement.

Data were collected in the University of Pittsburgh Brain and Communication Science Research Initiative (BASRI) space using an Eyelink 1000 eye-tracker. Participants were seated about 60 cm away from a 36-inch computer monitor with a resolution of 1440 x 900 pixels. The eye-tracker was positioned on a tabletop below the screen to track their left eye location. The specific distance from the eye-tracker to the eyes of the participant was based on and adjusted for individual participant factors, like height. Stimuli were presented using Experiment Builder v 2.3.38 software.

2.2.3 Procedure

Participants completed a screening questionnaire inquiring about demographic and personal information, including date of birth, sex/gender, years of education, race/ethnicity, native language. They also self-reported any cognitive, neurological, neuropsychological, or language conditions. Participants were also asked about vision status. The investigators performed a hearing screening at 500, 1000, 2000 Hz at 25 dB and 4000 Hz at 40 dB to confirm normal hearing. Participants were excluded if they had a history of neurological, cognitive, neuropsychiatric, or intellectual disorders. All participants passed the hearing screening and fit the inclusion criteria.

Following the screening procedures, eligible participants completed the VWP task. Participants were presented with the trials and stimuli described above.

2.3 Data Analysis & Statistics

Duration in milliseconds of gazes towards competitors vs. unrelated distractors were compared for younger and older adults to determine the presence of age-related differences between taxonomic and thematic semantic processing. Differences in taxonomic and thematic semantic processing were analyzed by comparing the duration of gazes toward taxonomic and thematic competitors compared to the unrelated distractor in both groups. Results regarding gaze patterns were then further analyzed to determine whether differences in gazes to taxonomic and thematic semantic competitors are more consistent with the Inhibitory Deficit Hypothesis or the Regression Hypothesis. Given the changes to sample size recruitment, results from both groups were compared via descriptive analysis (i.e., comparing the mean degree of taxonomic and thematic semantic competition within the groups) and case comparison (i.e., comparing the mean amount of competition for the one older participant to the means in the younger group). Limitations of the changes to analysis will be discussed below.

Original analysis methods planned to employ Growth Curve Analysis (GCA), which is used to investigate changes over a period of time (Mirman & Graziano, 2012). This analysis method allows for investigation into the effect of variables, such as age (older and younger) and competitor relatedness (thematic versus taxonomic), on gaze fixations over time. Separate growth analysis curves were planned to be created for each type of semantic competitor to determine the amount of competition posed by each type of semantic relationship. We planned to analyze the effects of age and semantic competitor type by using two GCA variables: the intercept (the proportion of overall gazes towards an image) and the slope (the speed at which gazes towards an image increase).

Given the previously discussed constraints, a combination of descriptive statistics and statistical analyses were conducted to analyze the data due to the changes to sample size. In line with the research questions posed by the study, cumulative gaze patterns were a more suitable measure than changes in gaze patterns over the course of a trial. Rather than analyzing time course changes in gaze patterns, the total time spent gazing at specific distractors or competitors over the course of a trial was used as the dependent variable to measure the degree of competition posed by taxonomic and thematic semantic competitors.

Descriptive data analysis was performed using PivotTables in Microsoft Excel to generate means for the average gazes to the unrelated distractor and semantic competitors for the younger group and older adult. For the younger group, additional statistical analyses were conducted using a mixed effect regression model in R. Mixed effect regression models were created to analyze: 1. Average differences in milliseconds spent gazing at each semantic competitor vs. the unrelated distractor across participants, 2. Average differences in milliseconds spent gazing at the taxonomic vs. the thematic semantic competitor across participants, and 3. Differences in milliseconds spent gazing at the taxonomic vs. the thematic semantic competitor for each individual participant.

For the mixed effect regression model analyzing average differences in gazes to the semantic competitor compared to the unrelated distractor, the object (i.e., type of distractor; C [unrelated], S [semantic]), semantic competitor type (i.e., sd_type; taxonomic [tx] or thematic [th]), and interaction between object and semantic competitor type were used as fixed effects, while the item (i.e., the specific stimuli presented in a given trial) and person (i.e., participant) were used as random effects. In the mixed effect regression model analyzing average differences in cumulative duration of gazes to the taxonomic vs. thematic semantic competitor, the semantic competitor type was used as a fixed effect variable, while the item and person were used as random effects. For the mixed effect regression model examining differences in gazes toward each type of semantic competitor for each individual participant, the semantic competitor type was used a fixed effect, while item and the slope of semantic distractor type (i.e., difference between thematic and taxonomic distractors) within persons were used as random effects. The random slopes of semantic distractor type were extracted from this model in order to examine differences in gazes toward each type of semantic competitor for each individual participant.

3.0 Results

3.1 Descriptive Statistics for Younger Participants

Results from descriptive statistics for the younger participants demonstrated that on average, younger participants spent more time gazing at the unrelated distractor than at the semantic competitor (Figure 3; mean unrelated = 155.94, mean semantic = 143.34).

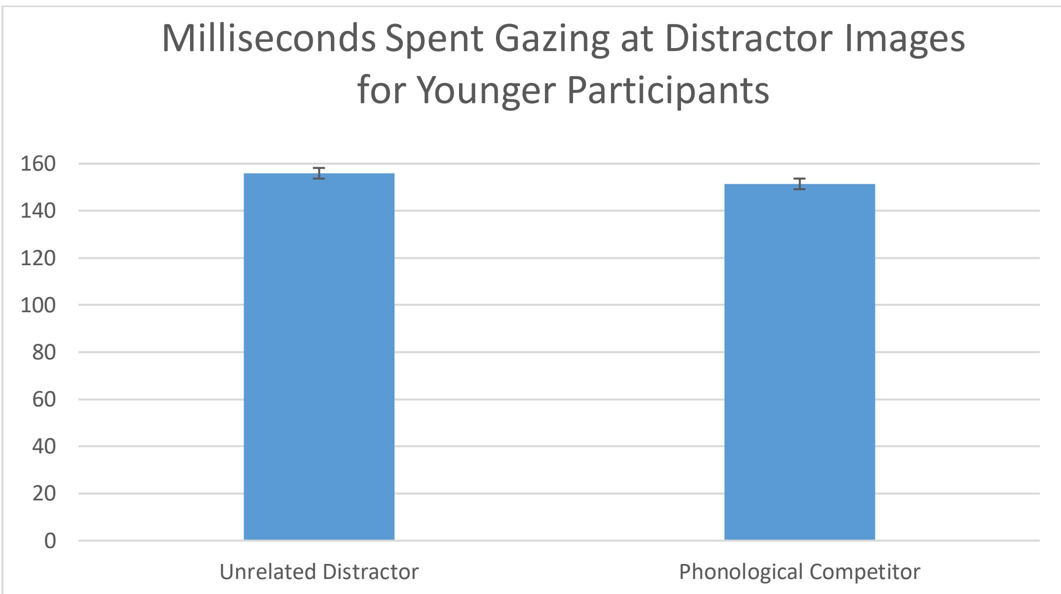

Figure 3. Gaze patterns for the unrelated distractor and semantic competitor for younger participants.

In trials with a thematic semantic competitor, younger participants spent more time gazing at the semantic competitor than to the unrelated distractor (Figure 4; mean th = 152.01, mean unrelated = 145.68). In contrast, during taxonomic trials, younger participants spent more time gazing at the unrelated distractor than at the semantic competitor (Figure 4; mean unrelated = 160.08, mean tx = 139.83).

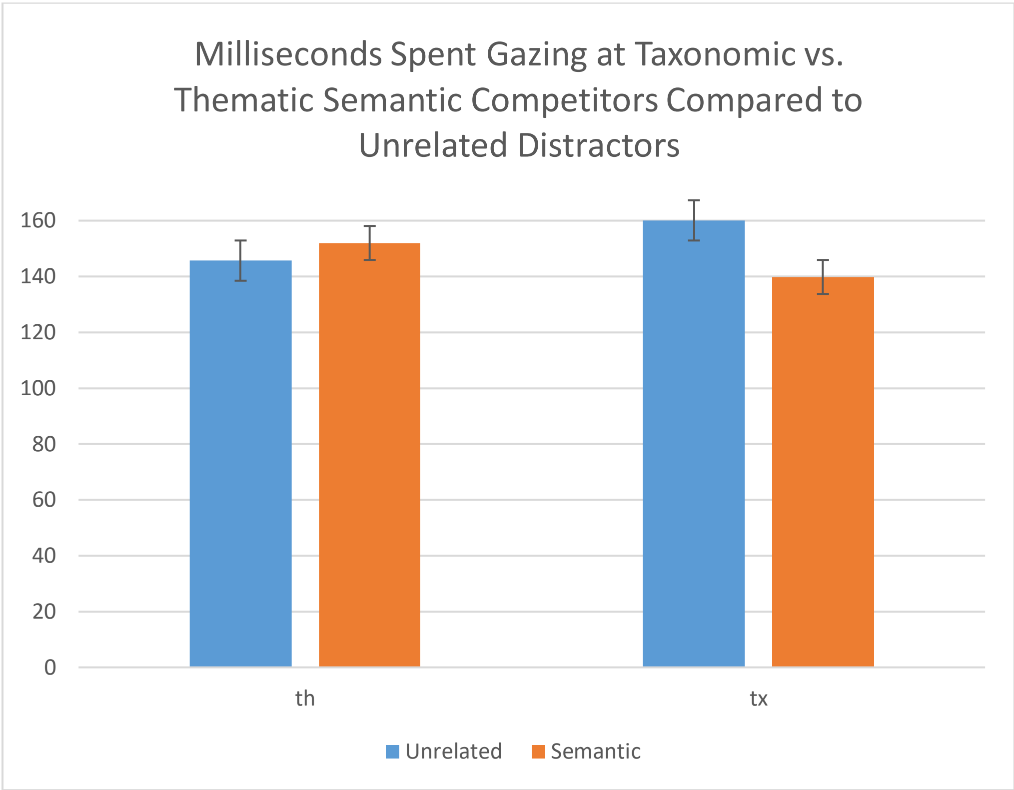

Figure 4. Gaze patterns for the unrelated distractor and semantic competitor in taxonomic vs. thematic trials for younger participants.

Further, younger participants spent more time on average gazing at the thematic semantic competitor than the taxonomic semantic competitor (Figure 5; mean th = 152.01, mean tx = 139.83).

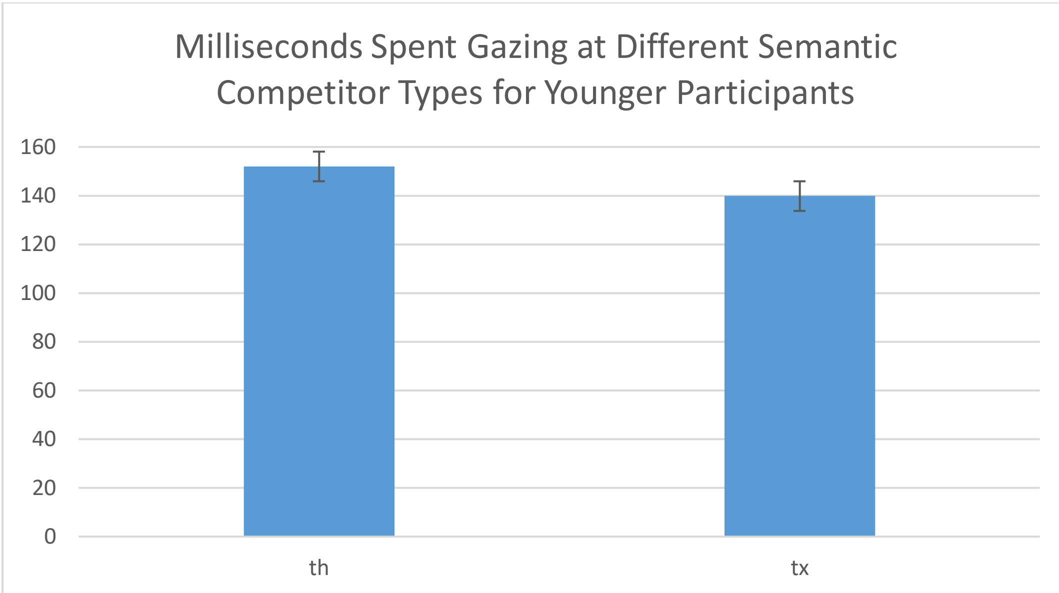

Figure 5. Gaze patterns for thematic (th) and taxonomic (tx) semantic competitors for younger participants.

3.2 Statistical Analyses for Younger Participants

Table 1. Mixed regression model for the duration of gazes to the unrelated distractor and semantic competitor.

	Estimate	Std. Error	t value
(Intercept)	149.514927247554	12.7964215367871	11.6841201907681
Object2	-6.96248600223964	16.0843295169101	-0.432873872356302
sd_type2	1.09073962756663	16.084961623617	0.0678111426741071
Object2:sd_type2	-26.5697088465846	32.1686590338202	-0.825950152869312

Table 1 presents the mixed effect regression model output for cumulative gaze patterns for each type of competitor for the younger participants. In this model, Object2 represents the difference between gazes to the semantic competitor (both taxonomic and thematic) and unrelated distractor, sd_type2 represents the average difference in gazes to the semantic competitor and unrelated distractor in trials with a taxonomic versus a thematic competitor, and Object2:sd_type2 captures the size of the difference between gazes to the semantic competitor and the unrelated distractor for trials with a taxonomic or thematic competitor.

Differences in gaze patterns to unrelated distractors vs. semantic competitors were considered significant if the t-value corresponding to each value was >2 or < -2. There were no significant differences between cumulative gazes to the unrelated distractor and either semantic competitor (Object2, t = -0.43). Similarly, the difference in gaze patterns between each semantic competitor and the unrelated distractor was not significantly different (Object2:sd_type2, t = -0.83). In other words, the difference in cumulative gazes was not significantly different when comparing differences in gazes to the taxonomic semantic competitor and unrelated distractor and gazes to the thematic semantic competitor and unrelated distractor.

Table 2. Mixed regression model for the duration of gazes to the thematic vs. taxonomic semantic competitor.

	Estimate	Std. Error	t value
(Intercept)	152.006578947368	18.7087486036727	8.12489291333617
sd_typetx	-12.1487102016039	23.7408255018909	-0.511722315664055

Table 2 presents the mixed regression model output for cumulative gaze patterns for thematic and taxonomic semantic distractors alone. This model was run on a subset of the data that removed gazes to the unrelated distractor and only examined gazes at the semantic competitor (taxonomic or thematic). In this model, the Intercept represents gazes to the thematic competitor and sd_typetx represents gazes to the taxonomic competitor. Differences in gaze patterns to unrelated distractors vs. semantic competitors were once again considered significant if the t-value corresponding to each value was >2 or < -2. There were no statistically significant differences between cumulative gazes to the thematic than the taxonomic semantic competitor (t = -0.51).

Table 3. Differences in gaze patterns to thematic and taxonomic semantic competitors for individual younger participants.

	grpvar	term	grp	condval	condsd
1	person	sd_typetx	101	-8.98513082930538	20.7976218557838
2	person	sd_typetx	102	9.72691473416982	20.882683940651
3	person	sd_typetx	103	-17.9276406566117	20.7135908321315
4	person	sd_typetx	104	-8.58309518241489	20.6305702069771
5	person	sd_typetx	105	-7.20991340612406	20.7135908321315
6	person	sd_typetx	106	31.9593877643939	20.7135908321315
7	person	sd_typetx	107	-1.18026356138063	20.7976218557838
8	person	sd_typetx	108	8.31288185260243	20.6305702069771
9	person	sd_typetx	109	-6.11314071532924	20.7135908321315

Table 3 depicts random slope effects within person for the second model above, in Table 2. These random effects extracted from the model reveal differences in individual gaze patterns for taxonomic and thematic semantic competitors. In this model, positive values indicate greater cumulative gazes in milliseconds to the taxonomic competitor, while negative values indicate greater gazes to the thematic competitor.

3.3 Descriptive Statistics for the Older Participant

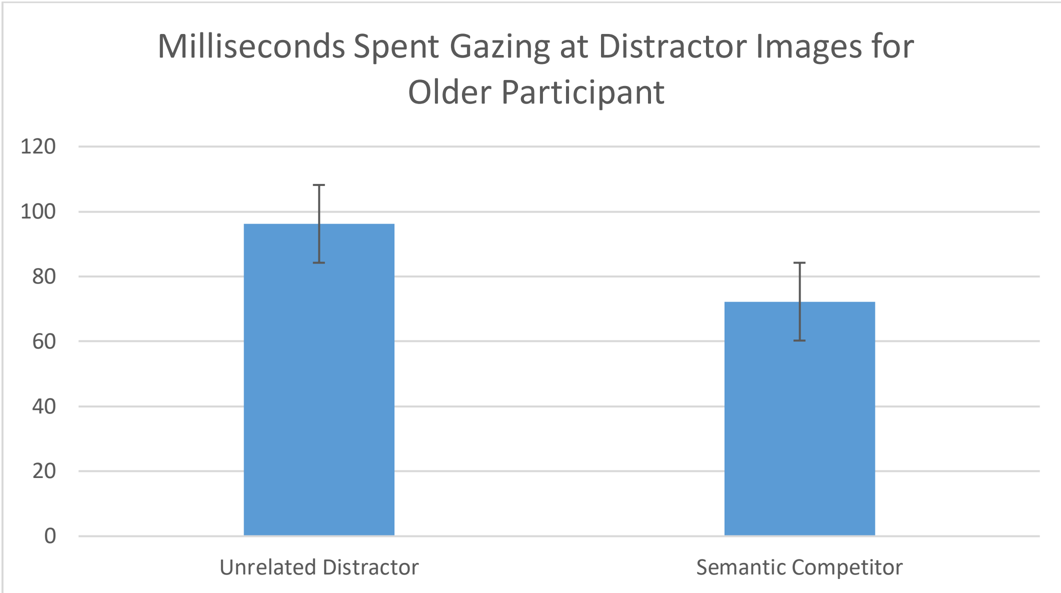

Figure 6. Gaze patterns for the unrelated distractor and semantic competitor for the older participant.

Descriptive analyses revealed that for the older participant, there was a greater number of milliseconds spent gazing at the unrelated distractor than the semantic competitor (mean unrelated = 96.19, mean semantic = 72.23).

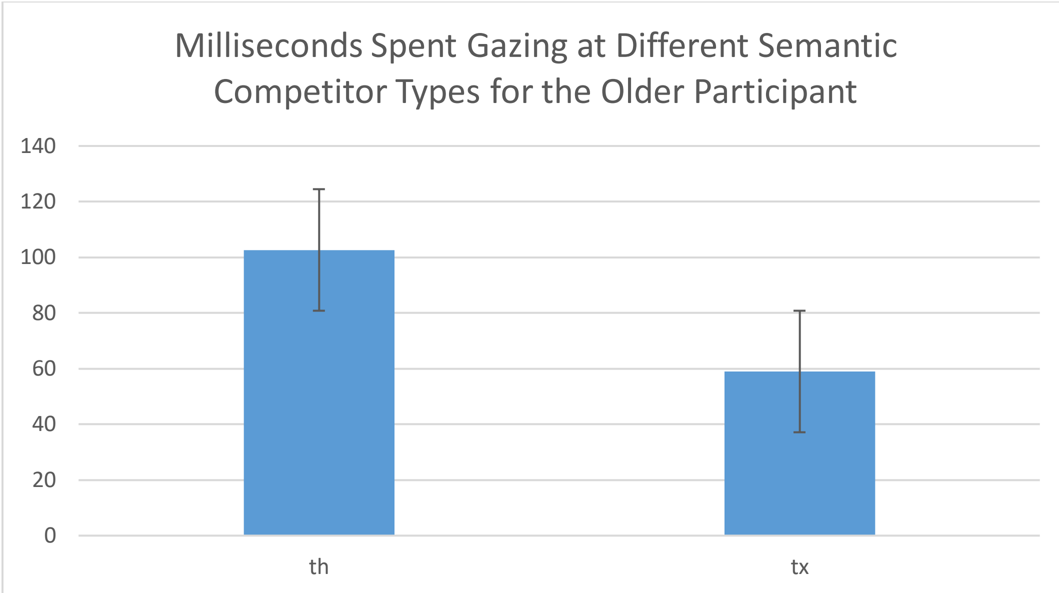

Figure 7. Gaze patterns for thematic (th) and taxonomic (tx) semantic competitors for the older participant.

Descriptive statistics also revealed that the older participant spent more time gazing at the thematic than the taxonomic semantic competitor (mean th = 102.65, mean tx = 58.97).

4.0 Discussion

The findings presented above provide preliminary evidence regarding changes to different types of semantic processing across the lifespan. We aimed to uncover the presence and nature of changes in semantic processing over the lifespan, as well as relate the findings to previously established hypotheses related to cognitive and linguistic processes. These preliminary results are inconclusive, and the discussion below presents the interpretation of these results if this study were replicated with a larger sample and greater power.

In investigating the presence of changes to semantic processing with age, we found differences in the degree of semantic competition posed by different types of semantic competitors for the younger adults compared to the older adult. Younger adults showed similar gaze patterns to both taxonomic and thematic semantic competitors. In contrast, the older adult showed greater competition from thematic than taxonomic semantic competitors. If these results were replicated, they would indicate that younger adults may have equivalent tendencies for taxonomic and thematic thinking, while increasing age leads to a preference for thematic semantic relationships.

As previously discussed, the Inhibitory Deficit Hypothesis, the Regression Hypothesis, or a combination of both hypotheses were intended to explain the findings of the results uncovered in this study. The proposed hypotheses in their entirety are unable map onto the findings reported here (assuming these results were replicated in a future study with a larger sample). Instead, the Regression Hypothesis is consistent with some our findings of increased competition from thematic semantic competitors for the older adult. However, our results are inconsistent with the other assertion of the Regression Hypothesis, which posits that younger adults have an increased salience towards taxonomic semantic relationships. Rather, our findings report equal competition from both taxonomic and thematic semantic relationships for younger adults.

Further statistical analyses revealed that, for the younger group, there were notable individual differences in competition from thematic and taxonomic competitors. If these findings were replicated, they would be consistent with those reported by Mirman et al. (2017) who discuss individual differences in the salience of thematic and taxonomic relationships. Despite considering the effects of age, education, and experience, individuals exhibit consistent inclinations towards either taxonomic or thematic semantic relationships (Mirman et al., 2017). These findings are important when considering our findings regarding equal competition from thematic and taxonomic competitors for younger adults, which are inconsistent with the Regression Hypothesis. These differences may be explained by the individual differences of the younger participants in this data set.

Unexpectedly, descriptive statistics in the present study also uncovered both younger adults and the older adult showed more gazes to the unrelated distractor than either type of semantic competitor (for the younger adults, the descriptive statistics revealed that this pattern did not hold for the thematic competitor: for trials with a thematic competitor, there were more gazes at the semantic competitor than the unrelated distractor.) These findings are inconsistent with the hypotheses posed above. These findings may be the result of the effects of individual stimuli being more appealing and, as a result, drawing more gazes. These differences may also reflect difficulties in calibrating the eye tracker for the older participant, as this was a difficult process while obtaining data from this individual. Consistent with this, results revealed that there were no gazes to the unrelated distractor in trials with a thematic competitor for the older adult. These results are unlikely based on stimuli alone, therefore we attribute them to challenges with calibration.

4.1 Limitations

It is important to note the limitations of our findings given the limited sample size. Our results do, however, provide preliminary findings regarding changes to semantic processing over the lifespan, moving from equal preference towards taxonomic and thematic semantic relationships, towards increased preference towards thematic thinking with increasing age. As previously noted, we were unable to obtain our desired sample size, which limits the power of the results reported here. Further, we were unable to run statistical analyses for the data obtained from the older participant because of these constraints. While the data reported here provide preliminary evidence for the existence of age-related differences in semantic processing, further work is required in a larger sample to validate and expand upon these findings.

Beyond sample size and statistics, limitations regarding materials and data collection measures are important to discuss, as well. While the stimuli images were normed for name agreement, we do not have normative data regarding the visual properties of the images. Specifically, we do not know how visually complex, colorful, or appealing these images were to subjects. Beyond linguistic relationships among the stimuli, visual image properties may also impact gaze patterns during the study. In addition, difficulties with calibration, particularly for the older participant in our sample, confound the sensitivity of the data obtained from this participant, as discussed above.

4.2 Future Directions

Future research may wish to focus on investigating changes in semantic processing over the lifespan with a sample that is larger and more representative of the entire population. The present study included two age groups, however, investigating semantic competition in middle-aged adults may provide valuable and more sensitive information about how semantic relationships change across the lifespan. Future work should also consider the impact of individual differences in semantic processing, as revealed in the analysis of the younger adults' differences in individual gaze patterns for taxonomic and thematic semantic competitors. It is important to consider these differences and their impact on general findings of changes in semantic processing across the lifespan.

5.0 Conclusion

This study investigated differences in taxonomic and thematic semantic processing over the lifespan and attempted to relate these findings to hypotheses related to lexical access in aging. We found preliminary evidence for equivalent preferences for taxonomic and thematic semantic relationships for younger adults, and increased preferences towards thematic relationships in an older adult. Descriptive statistics also revealed unexpected findings regarding increased gazes to unrelated stimuli than semantically related stimuli. Further work in a larger sample is required to validate these findings.

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