ABSTRACT

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Kathryn Tower, Master of Arts, 2011

Directed by: Dr. Yasmeen Faroqi-Shah, Department of Hearing and Speech Sciences

As the U.S. population ages, the need to understand how language changes with age becomes more important. Difficulty with word retrieval is one of the most notable changes as individuals age (Burke & Shafto, 2004); however, theoretical models of aging disagree on the cause. Two prominent theories are the *impaired lexical access hypothesis* and the *general slowing theory*. The present study aimed to explore these two ideas using magnetoencephalography (MEG). A young adult group (N=17, mean age 20.6 years) and an older adult group (N=9, mean age =64.6 years) participated in a lexical decision task using verbs. MEG latency data corresponding to lexical access found no between-group difference. Behavioral response times were significantly slower in the older group. Results point either to the idea that linguistic difficulties experienced by older individuals are the result of reduced abilities in phonological or motor processing, or that while lexical representations remain intact, the connections between them become less efficient with age.

THE EFFECTS OF AGING ON LEXICAL ACCESS

By

Kathryn Tower

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Advisory Committee:
Dr. Yasmeen Faroqi-Shah (Advisor)
Dr. Nan Bernstein Ratner
Dr. Rochelle Newman

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Introduction

In 2000, the national Census reported that 12.4% of the population was over 65 years of age, and in 2009, it was estimated that 12.9% of the population was over 65 years of age (U.S. Census Bureau, Population Estimates Program, 2009). The U.S. population is aging, and questions about how language changes with age are becoming increasingly important.

One of the earliest observable changes as individuals age is increased difficulty with word retrieval (Burke & Shafto, 2004). Although it is documented that word retrieval difficulties exist in the aging population, the exact nature of the problem has not yet been defined. Some researchers point to reduced access to lexical representations (Myerson, Ferraro, Hale, & Lima, 1992; Sommers, 1996), while others propose a breakdown in access to phonological codes, as is commonly experienced in the tip-of-tongue (TOT) state (Burke et al., 1991; Burke & Shafto, 2004; Nicholas, Obler, Albert, & Goodglass, 1985). A number of researchers argue that impaired access to lexical or phonological representations is not the source of linguistic difficulties experienced by older adults; rather, there is a global reduction in processing speed, resulting in slowed word retrieval (Craik & Byrd, 1982; Myerson et al., 1992). Many studies on word retrieval in aging utilize behavioral research methods to quantify difficulties that older individuals have with speed and accuracy of picture naming and lexical decision tasks, and results disagree about a specific cause for the decreased performance of older adults (Almor, Kempler, Anderson, &MacDonald, 2005; Moberg, Ferraro & Petros, 2000; Morrison, Hirsh, & Duggan, 2003; Nicholas et al., 1985; Ramsay, Nicholas, Obler, &

Albert, 1999). The present study seeks to examine if speed of lexical access may be impacted in aging by using a temporally sensitive brain imaging technique called magnetoencephalography (MEG), which measures magnetic fields generated by electricity conduction through neurons. Further, most prior studies have examined noun retrieval, probably because most nouns can be both pictorially simple, therefore convenient for research design, and are also important content words. However, verbs also play a vital role in communication and there is reason to believe that verbs are processed differently than nouns (Perani, Capa, Schnur, Tettamanti, Collina, Rosa, & Fazio, 1999; Warburton, Wise, Price, Weiller, Hadar, Ramsay, & Frackowiak, 1996). Yet, very few studies of aging include verbs. Hence, relatively little is known about how verbs are impacted by aging, particularly whether or not verbs are accessed with the same speed as we age. The study proposed for this thesis seeks to specifically examine differences in verb access with aging using MEG. To our knowledge, this is among the first examinations of verb access in the elderly with MEG. It is likely that MEG may reveal detailed information about timing and location of brain activity that cannot be obtained through alternative means, hence providing a greater understanding of the true nature of word retrieval difficulties.

In the following sections, linguistic aspects of aging will be reviewed, with particular focus on lexical differences in order to better understand the possible mechanisms underlying word access in aging. This will be followed by a brief section on neural changes with aging (encompassing both structural and functional imaging). Then, selected brain imaging studies of lexical access will be discussed, with a specific focus on

MEG. Finally, there will be a brief overview of the known differences between noun and verb processing.

Language and Aging

Theoretical perspectives on language in aging

Several theories have been proposed to explain the language-related changes that occur with aging, some of which relate to reduced access to lexical or phonological items and others which relate to overall processing speed. One theory posits that older adults have reduced inhibitory capacity. Therefore, the brain has more difficulty selecting the correct item from the mental lexicon, since more potential responses are activated (Sommers, 1996). A second theory, the diminished-resource hypothesis, proposes that older individuals have reduced processing resources. As a result, individuals may not have enough cognitive resources to devote to a specific task, or may allocate the limited resources inappropriately (Craik & Byrd, 1982). One variant of the diminished resources hypothesis is that linguistic resources are specifically inefficient, hence affecting *access to lexical representations* (Burke & Shafto, 2004). The direct consequence of impaired access to lexical representations is difficulty with retrieving words while speaking. Another very prominent account is a *general slowing theory*. This theory holds that with aging comes reduced cognitive efficiency, resulting in slower processing for both linguistic and nonlinguistic tasks (Myerson et al., 1992). Both the impaired lexical access and the general slowing theories would result in slower retrieval of lexical items in older individuals. Obviously the general slowing theory predicts additional slowing down of other nonlexical and cognitive operations such as auditory and visual processing and motor planning. It is as yet unclear if any of these hypotheses better account for lexical access difficulties in elderly individuals. The present study attempts to closely examine performance on a lexical decision task, in order to determine whether general slowness is demonstrated by older individuals, or if impaired access to lexical or phonological representations is the cause of reduced language processing speed. These two theories will be revisited in later sections in the context of predictions for the present study.

Empirical findings on language in aging

Older adults have been shown to use and process language differently than younger individuals (Botwinick & Storandt, 1974; Burke, MacKay, Worthley, & Wade, 1991; Davis & Ball, 1989, Morrison et al., 2003; Nicholas et al., 1985; Obler, Fein, Nicholas & Albert, 1991; Ramsay et al., 1999). A wide variety of language measures have been shown to decrease with age, including the ability to define words (Botwinick & Storandt, 1974), discourse production (Kynette & Kemper, 1986), and comprehension of complex syntax and implausible sentences (Davis & Ball, 1989, Obler et al., 1991). In tasks that require delayed recall of information presented verbally, it has been shown that processing speed decreases significantly between ages 20 to 60 years (Yankner, Lu, & Loerch, 2008). One of the most widely observed and reported difficulties that begin to emerge as individuals age is word finding difficulties; indeed, research shows that the TOT phenomenon increases with age (Burke et al., 1991).

Because word finding problems and TOT phenomena are some of the earliest and most observable issues that occur with aging, lexical access may be considered one of the most relevant aspects of language to explore in the context of aging.

Lexical Access in Aging

As mentioned earlier, most prior research on lexical access has examined nouns, using either picture naming tasks or lexical decision tasks (in which participants decide if a presented word is real or not). Because previous studies have relied mainly on nouns as stimuli for investigations of lexical access, a review of the literature will discuss findings based on noun studies, highlighting studies utilizing verbs whenever possible. Research into how lexical access is affected by aging shows that there are differences in the ways that older individuals access the lexicon. This research has largely utilized behavioral methodology, in which participants are asked to name pictures. This is a production task that incorporates access to both semantic and phonological knowledge into the end goal of word production. Following the meta-analysis by Indefrey & Levelt (2004), a general model for picture naming involves visual processing, lemma retrieval/selection, retrieval of phonological code, syllabification, and, finally, articulation. A second empirical task, lexical decision, has been used to focus more specifically on lexical access without the potential confounding factor of phonological encoding and articulatory planning processes, but with the requirement of making a decision on lexicality and indicating the decision by means of a button press response.

Word production studies

Word production tasks demonstrate that older adults are slower and less accurate than younger individuals (Morrison et al., 2003; Moberg et al., 2000, Nicholas et al, 1985; Ramsay et al., 1999). Two experiments by Morrison et al. (2003) demonstrated that older adults were slower and less accurate at naming verbs than younger individuals. In the first experiment, college students (mean age 19.6 years) and older adults (mean age

75.5 years) were asked to provide verbal labels for pictures depicting actions. Analysis of the data showed that older adults made more total errors and produced a wider variety of erred responses than younger adults. Furthermore, word frequency had a much more significant impact on older adults' performance than on younger adults'. In addition, older adults were affected significantly by visual complexity of the stimuli. Because older adults were slower to name more visually complex pictures, researchers posit that they were slower to process and identify the action being shown. The second experiment involved similar groups of undergraduate students (mean age 21.2 years) and older adults (mean age 74.2 years). Participants were asked to orally read written words. Older adults still demonstrated longer response times than younger individuals. Researchers argued that older individuals' performance in the two experiments (slower response time when dealing with more complex stimuli, and slower naming and reading) provide support for the general slowing hypothesis. However, the faster naming latencies for higher (as opposed to lower) frequency words suggest that lexical access may be impaired, especially for lower frequency items because word frequency is considered by the authors to be a lexical variable. Hence the findings of this study did not differentiate between general slowing and lexical hypotheses of aging. Because the authors did not find any relationship between variables of age and stimulus type (picture vs. written word), they reject the idea that slower response times in older adults may be a result of a task-related deficit not directly examined (for example, motor planning for speech).

The finding that older adults are affected by word frequency was replicated by Almor et al. (2005). Their study required oral reading of written verbs, and it was found that older adults' performance was affected by frequency of verbs when compared to that of younger individuals. This supports lexical access as the point of breakdown in word processing, since, as previously mentioned, word frequency is a lexical variable. In contrast, a study by Newman & German (2005) compared naming abilities of adolescents, young adults (ages 20-49 years) and older adults (aged 50+ years). They concluded that age of acquisition and familiarity of the words, rather than frequency, played a significant role in the performance of older adults.

The first of a two-part behavioral study using the Boston Naming Test (BNT) compared the performance in a word naming task of 23 college-age adults (mean age of 22.17 years with range of 19-36 years), to that of 25 older adults (mean age of 68.16 years with range of 60-91 years), all of whom were screened for a history of neurological disease and handedness (Moberg et al., 2000). Participants were asked to verbally name picture stimuli from the BNT. Response latency and accuracy were recorded. Older adults demonstrated a longer response latency than the young adult group. However, no significant difference between older and younger adults regarding accuracy was found. It is unclear whether the slower responses were due to overall slowed processing or slower access to lexical representations. The second part of the study involved a lexical access task that will be discussed later.

Another study that examined aging using the BNT found slightly different results. Nicholas et al., (1985) investigated naming abilities across different age groups. Four cohort groups were tested: 30-39 years, 50-59 years, 60-69 years, and 70-79 years. Researchers tracked accuracy of initial response, error type, and how well participants responded to cueing. Stimuli included both nouns (from the BNT) and verbs (from the Action Naming Test (ANT)). The study demonstrated that older adults showed overall decreased naming abilities, especially after age 70. All groups accurately named more verbs than nouns. In addition, performance on the BNT (nouns) declined more significantly than on the ANT (verbs) with age. The change from the 30s group to the 70s group was 89.3% correct to 79.5% correct for the BNT; 94.3% to 89.1% for the ANT.

A longitudinal study by Ramsay et al. (1999) also examined verb naming using the ANT. In their study, the naming skills of 66 individuals (ages 30-79 at the beginning of the study) and how those skills changed over a 7 year period were investigated. Participants were screened for handedness, neurological illness, vision and hearing acuity, and cognition. The ANT was administered to each participant 3 times over a 7 year period. Participants were divided into 4 groups based on age at initial testing; 30s, 50s, 60s, and 70's. For each group except the 30s, response accuracy decreased significantly over time. By the third testing, the 60 year olds' performance was significantly worse than the 30-year-olds', and the 70-year-olds' performance was significantly worse than both the 30-year-old and the 50-year-old groups.

The Nicholas et al. and Ramsay et al. studies both found similar error patterns in the naming abilities of older adults. Both studies found that older adults frequently mislabeled verb pictures using semantically related verbs. In addition, Ramsay et al. (1999) found that older adults were more likely to produce a noun-for-verb substitution. Authors suggested this pattern may have been due to the task constraints or due to better accessibility of nouns. In their study, older individuals also demonstrated increased perseveration when compared to younger individuals; however, perseverative responses were generally in reference to semantically related pictures (e.g., "running" vs. "racing"). Additionally, Nicholas et al. (1985) observed circumlocutions more frequently in older adults. Because they noticed that verb errors were most frequently either semantically related verbs or circumlocutions describing the target verb, the authors hypothesized that the difficulty in word retrieval was not related to incorrect semantic representations; rather, the participants had difficulty accessing other word characteristics (phonology, grammatical encoding, etc.). Thus, the Nicholas et al. study supports the reduced lexical access theory. Researchers furthermore suggested that naming abilities in older adults decrease due to difficulty with lexical retrieval, and that circumlocutions in testing and conversation may reflect a learned coping mechanism. Finally, researchers found that older adults responded better to phonological cues than to semantic cues when struggling with word retrieval, suggesting that word retrieval is more compromised by difficulty accessing the phonological representation rather than the lexical representation. Other studies, however, suggest that areas besides the phonological system may contribute to lexical access difficulties (Almor et al., 2005). When interpreting these studies, it should be kept in mind that behavioral picture naming tasks incorporate multiple cognitive and linguistic processes (picture recognition, phonology, semantics, motor planning, etc.) and hence add many confounds in interpretations about the process of lexical access per se.

Ramsay et al. (1999) found that older adults were less accurate in naming verbs than their younger counterparts. However, despite decreased performance, typical adults were shown to score above 90% accuracy on verb-naming tasks; thus, in conversation they are unlikely to experience significant difficulties (although they do have TOT states more often than younger individuals). Authors of this study hint that lexical access is impaired during the normal aging process; however, even the most degraded performance was characterized by 90% accuracy. Both this study and that of Nicholas et al. measured only accuracy of naming. However, examining response latency may more accurately represent older adults' experiences with language, since significant delay in access can significantly impact one's ability to keep up with the quick pace of normal conversation.

The majority of studies exploring word retrieval using picture naming tasks in older adults provide results that support the reduced lexical access theory (Almor et al., 2005; Nicholas et al., 1985; Ramsay et al., 1999). Authors of these studies conclude that access to lexical or phonological encoding is reduced, or in some cases, that the representations themselves are not intact. However, the nature of the experiments themselves may create a bias toward these conclusions and away from conclusions pointing to a general slowing theory. Picture naming tasks, for example, incorporate visual processing, semantic selection, and potentially the application of grammatical rules, phonological encoding, and motor planning. Given the many processes involved in this task, it is impossible to determine the level at which breakdown occurs; hence, one cannot distinguish between impaired lexical access and general cognitive slowing. Because all word production tasks necessarily require phonological output, a more direct method of investigating lexical access is through lexical decision tasks.

Lexical decision studies

An early study of aging and lexical access utilized lexical decision in which participants were asked to push a button to indicate lexicality of frequent, infrequent, and pseudo-words (Bowles & Poon, 1981). Stimuli included 60 high-frequency English nouns, 60 low-frequency English nouns, and 60 orthographically legal pseudowords. To control for sensorimotor skills, a button press task that measured choice reaction time without lexical decision was administered as well. Although results of the lexical decision task indicated significantly slower responses in older individuals, choice reaction times were also significantly slower, so researchers concluded that aging did not affect the speed of lexical access. Instead, they attributed the slowing to sensorimotor deficits that increase with age and to more frequent words being recognized more quickly by older adults than by younger individuals.

Subsequent studies found similar results, but did attribute slower reactions to degraded word retrieval skills in older adults. Moberg et al. (2000) used a lexical decision task with 23 college-age adults (mean age of 20.61 years with range of 18-36 years) and 31 older adults (mean age of 66.90 years with range of 60-75 years). BNT stimuli words (nouns) were used, along with orthographically valid pseudo-words. Individuals with significant error rates (more than 10%) were not included in the statistical analysis of latency data. Again, the older group demonstrated slower latency compared to the younger group.

Additional studies have yielded similar conclusions while also demonstrating that older adults process lexical items in different ways than younger individuals. Taler and Jarema (2007) published a behavioral study in which 11 cognitively intact older adults (mean age 75 years) and 10 younger adults (mean age 27 years) performed a lexical decision task on mass nouns, count nouns, dual nouns (which can be used as either mass or count nouns, e.g., *lamb*), and matched pseudo-words. Participants were to respond to real words; no response was required for a pseudo-word. The study found that older adults demonstrated slower response times overall and produced more erred responses than their younger counterparts. In addition, older adults recognized dual nouns more quickly than count nouns, a pattern that was not observed in younger individuals. Results of the study indicate that age may increase lexical access time, but also that older adults may organize and/or access the lexicon differently than younger adults do. Finally, latency of response time when faced with singular nouns was less than when plural nouns were presented for all participants (both young and old), indicating that words containing more than one morpheme take longer to recognize. Differences in how quickly and accurately older and younger adults recognize various types of words may point to an altered lexical system in older adults. Specific differences in processing give support to a theory of impaired (or perhaps altered) access to lexical or phonological items. Measures of lexical access reaction time, however, are vulnerable to confounding variables, as with any behavioral task, such as motor coordination and speed (for button press) or reading ability.

The majority of lexical decision studies investigating the effects of aging employ nouns as stimuli. However, the work of Kavé and Levy (2005) used verbs in a lexical decision task to study the effects of aging on linguistic processing in Hebrew speakers. Forty-eight young adults (mean age 23.04 years) and 48 older adults (mean age 74.48 years) were asked to press a button to indicate lexical decision when presented with either real verbs or pseudoverbs. Researchers found that the older adults responded more slowly than the younger group. The authors suggest this may be explained by the general slowing theory, or by the theory that older adults have reduced inhibitory control and therefore spend more time rejecting irrelevant information.

To summarize findings on word retrieval in aging, picture naming studies have found less accurate naming and lexical decision studies have found slower response time with age. However, given that multiple linguistic, cognitive and motoric operations are involved in picture naming and lexical decision, the reason why word retrieval is impaired is unclear. Is it due to specific difficulty with lexical access or a more global reduction in processing speed? An automatic measure that does not depend on overt responses from the participant is likely to be informative in teasing apart lexical access vs. global slowing. Through temporally sensitive neuroimaging methods such as event-related potential (ERP) and MEG, we can gather information about word retrieval without relying on verbal or motor responses. A number of studies have been conducted using neuroimaging techniques that examine lexical access in young adults (Obler, Rykhlevskaia, Schnyder, Clark-Cotton, Spiro, Hyun, Kim, Goral, & Albert, 2010; Papanicolaou, Pazo-Alvarez, Castillo, Billingsley-Marshall, Breier, Swank, Buchannan, McManis, Clear, & Passaro, 2006; Persson, Sylvester, Nelson, Welsh, Jonides, & Reuter-Lorenz, 2004; Reuter-Lorenz, 2002). As in the case of behavioral studies, the majority of studies to date have focused on nouns, with little work having been done on verbs. Prior to describing findings of lexical access using neuroimaging, neural changes with aging will be overviewed.

Neural changes with aging

Structural changes

Through the course of normal aging, the brain undergoes a variety of well-documented changes, some of which can logically be linked to language processing and overall processing speed. General physical changes affecting the brain have been observed through neuroimaging studies. Kemper (1993) reported that aging results in decreased brain weight, ventricular dilation, and loss of myelin. Areas of the brain specific to language have been shown to go through changes that mirror those of the brain as a whole. In their review of neural changes in aging, Nicholas, Connor, Obler, and Albert (1998) concluded that areas of cortical atrophy include the parasagittal gyri and adjacent frontal and parietal lobes. In addition, loss of dendrites related to age has been demonstrated in the posterior superior temporal gyrus, primarily in the left hemisphere (Anderson & Rutledge, 1996).

More recent research shows that all areas of the brain do not undergo equivalent changes during aging. Grey matter density (GMD) can be measured using MRI scans in combination with 3-D modeling and mathematical algorithms comparing the amount of grey matter to total brain volume, and it represents a key area of change in the aging brain. A study of 465 normal adults (ages 17-79 years) using MRI and voxel-based-morphometry to examine grey matter, white matter, and cerebrospinal fluid volume changes found that overall, GMD decreased linearly over the lifespan while white matter density did not change (Good et al., 2001). Examining the results more closely reveals that specific areas of the brain (angular gyri, pre- and post-central gyri, insula, and anterior cingulate cortex) lost grey matter density more quickly than others, while different areas (amygdala, hippocampi, entorhina corticies, and lateral thalami) retained grey matter density longer.

Area-specific differences have also been found in the left temporal lobe, an area identified as central to language processing. For example, Sowell, Peterson, Thompson, Welcome, Henkenius, and Toga (2003) performed an MRI study of 176 participants, ages 7-87 years, to investigate changes in GMD with aging. Overall, they found that GMD decreases over the lifespan; however, this trend is different in the left posterior temporal region of the brain. Here, it was seen to increase until age 30 before it began to decline.

At the same time, researchers measured the amount of white matter in the brain and discovered that white matter increases on average until age 40, suggesting that GMD decline prior to age 40 may be due to increased myelination and more efficient processing, while after age 40 myelin levels decrease and neural processing becomes less efficient. Researchers hypothesized that the decrease in GMD in the language regions of the brain beginning at age 30 reflects late maturation of that area in the form of "late" myelination.

Sowell et al. (2003) were careful to note that white matter in areas of the brain that are more anterior and used for language production and word retrieval (such as Broca's area) peak and decline earlier than other language-related areas (areas responsible for language comprehension) located in the posterior temporal lobe. This finding may help explain why word finding difficulties are routinely observed as individuals age, with no (or very few) concurrent comprehension difficulties.

Decreases in cortical thickness have been observed in recent studies. As in other investigations, researchers have found that the cortex undergoes different changes in different regions. A longitudinal study of 66 individuals, initially ages 60-84 years, used MRI data to reconstruct an image of cortical surfaces and identify changes over an average of 8 years (Thambisetty, Wan, Carass, An, Prince, & Resnick, 2010). Researchers found that, over time, cortical surface thickness decreased significantly more in the left hemisphere than in the right. In addition, the frontal and parietal lobes were shown to decline in thickness more quickly than temporal and occipital lobes, providing further support to the idea raised by Sowell et al. (2003) that more posterior regions related to language comprehension (such as the posterior superior temporal gyrus) are preserved and retain normal function longer than more anterior portions important for language production (such as Broca’s area).

Overall, it seems that language-specific regions of the brain mature and decline more slowly than other regions, with anterior perisylvian regions preserving a more robust structure longer. These findings provide physical evidence that can help explain why older adults often have difficulty with word finding tasks, but typically retain intact comprehension skills. However, we do not yet know at what level language processing breaks down and results in these production difficulties.

Functional changes

An earlier section of this paper showed that linguistic performance is affected by aging, and significant research has been devoted to identifying the specific functional changes that result from neurological changes. It is a logical assumption that decreases in grey matter density and cortical thickness in aging brains may lead to degraded abilities, and research into this topic supports the idea. For example, when performing memory and matching tasks, older adults demonstrate performance differences that can be linked to altered neurological functioning. Specifically, older individuals show increased activity in the prefrontal cortex and right hemisphere when performing verbal working memory tasks (Reuter-Lorenz, 2002).

A recent study by Obler et al. (2010) compared naming performance to structural characteristics in older adults. Twenty-four participants, ages 56-79 years, were given both the Boston Naming Test (BNT) and the Action Naming Test (ANT), and subsequently underwent MRI scanning, DTI imaging, or both. Correlations were found between performance on the ANT and grey matter volume in the left mid-frontal gyrus, right angular gyrus, and right middle temporal gyrus. BNT response time was negatively correlated with grey matter volume of the left mid-frontal gyrus and left planum temporale. White matter density was correlated with increased speed and accuracy for both the BNT and ANT. These results establish a clearer link between performance and structural changes. More importantly, increased right hemisphere activity was noted in older participants, indicating that older adults utilize more areas of the brain in lexical retrieval tasks than younger adults. These findings provide evidence for reorganization of the lexical system with aging. Lexical items may be represented more diffusely throughout the brain in older adults, and not strictly confined to perisylvian language areas as is classically noted in younger adults. It is therefore likely that online MEG imaging of older adults will reveal increased activity in the right hemisphere and frontal areas of the brain associated with lexical tasks.

Investigations using non-linguistic stimuli yield similar results. In a functional magnetic resonance imaging (fMRI) study investigating differences in digit-symbol processing in aging, a group of 19 younger adults (18-31 years) performed more quickly and accurately than a group of 19 older adults (50-69 years) (Motes, Biswall, & Rympa, 2011). Data indicated that the prefrontal cortex was a key area of change in processing efficiency, with younger participants showing reduced activity when they performed better, while older adults demonstrated increased prefrontal activity as accuracy increased. It is clear that older individuals recruit more parts of their brains in order to be more successful processors. Such evidence supports the idea that older adults engage in cognitive tasks in a way that is fundamentally different from younger adults.

Neuroimaging of Lexical Access

As neuroimaging techniques have become more widely available, they have been increasingly utilized to study lexical access. While it is impossible to eliminate all extraneous skills and processes from a behavioral task (motor planning, visual processing, etc.), neuroimaging allows researchers to better isolate skills pertaining directly to lexical access. Neuroimaging techniques, such as fMRI, are sensitive to neural regions associated with lexical processing, while other techniques such as ERP and MEG are sensitive to the time course of lexical activity. MEG measures magnetic fields generated by electricity conduction through neurons. Temporal resolution is high, demonstrating a timeline similar to that of EEG and ERP, but with the advantage of better spatial resolution.

A meta-analysis of spatial and temporal findings of neuroimaging studies of picture naming by Indefrey & Levelt (2004) revealed that it takes about 175ms to activate the concept related to a picture, and that a target lexical item is selected in the medial left middle temporal gyrus within 150-225ms after picture presentation. Between 200-400ms, activation spreads to superior parts of the posterior temporal lobe to retrieve the phonological code of the target picture name. Further phonological and phonetic planning occurs in the 400-600ms time window in the left inferior frontal gyrus. This is shown in Figure 1 (from Indefrey & Levelt, 2004). Given that phonological information is accessed in the 200-400ms time window in the left superior temporal gyrus (STG), this neural activity may be a likely candidate for aging effects, assuming that the phonological code is less accessible in the elderly. This idea will be revisited later in this section.

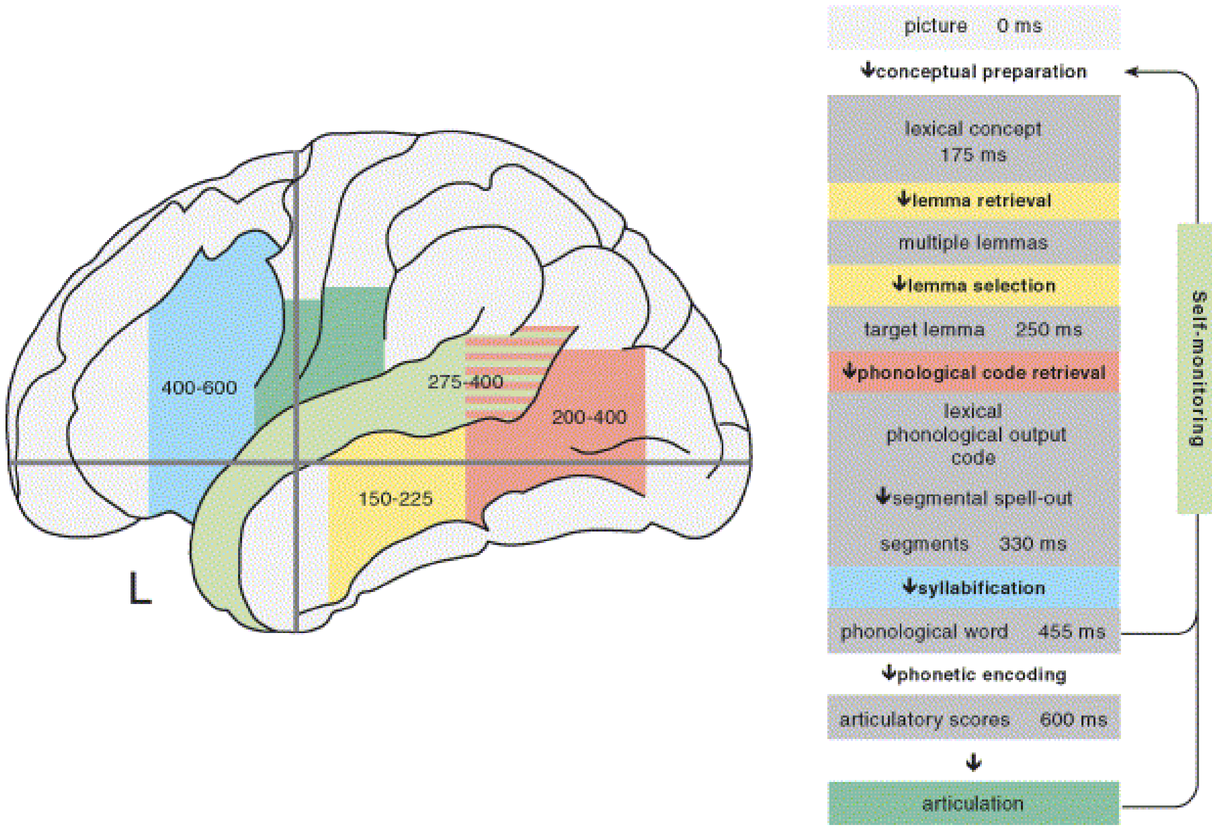

Figure 1. Spatiotemporal map of word processing during picture naming activities (Indefrey & Levelt, 2004).

Studies of lexical access using MEG, especially by Pylkkänen and colleagues, have also identified the 300-400ms time window as being sensitive to lexical access (Pylkkänen & Marantz, 2003; Pylkkänen, Stringfellow & Marantz, 2002).When words are visually presented during MEG recording, three prominent peaks are identified, as shown in Figure 2. The first, M170, seen at approximately 170ms after word onset and located bilaterally in the occipital lobe, is thought to reflect visual processing of written words because it is observed specifically for letter strings rather than symbols (Pylkkänen & Marantz, 2003; Stockall, Stringfellow & Marantz, 2004). The next peak, M250, reflects activity in the left temporal lobe and may indicate pre-lexical processing, but is inconsistently observed across participants (Pylkkänen & Marantz, 2003). The final peak, M350, is also located in the left hemisphere. It is assumed to indicate access of the mental lexicon and to represent true lexical access because it is sensitive to lexical properties such as word frequency, phonological neighborhood density, and repetition (Embick, Hackl, Schaeffer, Kelepir, & Marantz, 2001; Pylkkänen & Marantz, 2003; Solomyak & Marantz, 2009). Further, a study by Pylkkänen, Stringfellow & Marantz (2002) indicated that M350 is sensitive to early automatic lexical access and not to lexical competition. Researchers use amplitude of peaks, latency of peaks, total energy within a given time period, or localization of activity as dependent variables to evaluate lexical access, although it should be noted that there is some debate in the literature over the exact timing of individual peaks.

As previously mentioned, both lexical and phonological access are frequently found to be impaired with aging while semantic access is found to be relatively intact. Because the M350 has been shown to be sensitive to lexical and phonological variables, but not semantic ones, it is likely that age-related changes will be reflected in M350. Hence, in an attempt to investigate lexical access changes that occur with aging the present study examines age effects on M350.

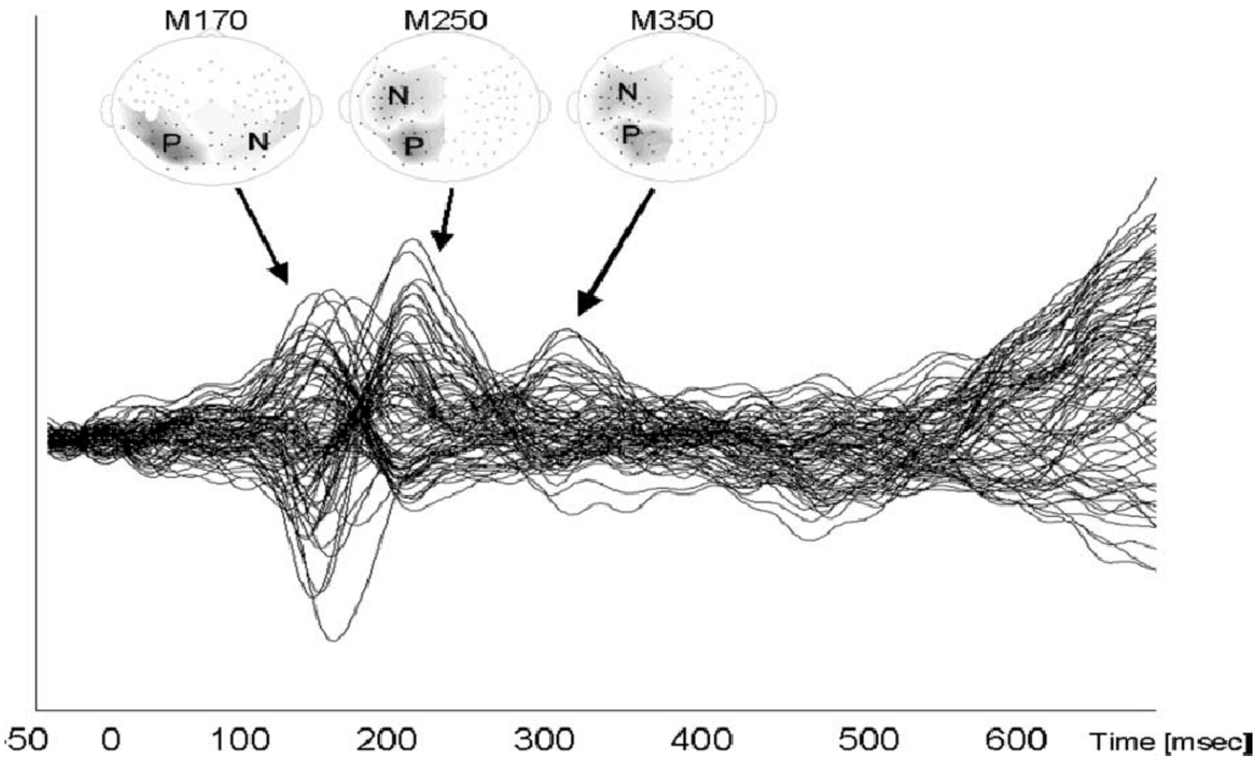

Figure 2. Peaks of activity in lexical access of visual words (Stockall, Stringfellow & Marantz, 2004)

Neuroimaging studies of factors affecting lexical access

Previous studies have revealed that aging has a significant effect on speed of lexical access, and that older adults demonstrate different neurological patterns than younger individuals when performing the same lexical tasks. It has also been established that, in addition to aging, lexical access is affected by morphological complexity (Pylkkänen & Marantz, 2003; Solomyak & Marantz, 2009).

A comprehensive study by Papanicolaou et al. (2006) incorporated five similar, but slightly different, tasks using MEG to identify neurological language maps of individuals of varying ages. Three experimental tasks involved auditory word recognition. Comparisons of these three studies revealed that, although both the middle temporal gyrus (MTG) and perisylvian regions were activated in older and younger adults following presentation of auditory language in the form of single words, latencies of activation of these regions in the right hemisphere were reduced as age increased. MTG activity was lateralized to the left, with no age-related difference in lateralization. Furthermore, older adults demonstrated less total activation as well as a decrease in latency of activation of the superior temporal gyrus in response to auditory language when compared to younger adults. No age effects could be determined in tasks that involved visual presentation of stimuli (including a visual word recognition task and a non-word reading task), because all participants in both experiments were children. Indeed, the intent of the Papanicolaou et al. study focused more on establishing language processing profiles using MEG than on making between-group comparisons. Age-related comparisons were made between groups that did not demonstrate large age differences and participated in slightly different experimental tasks and therefore, as pointed out by the authors, such results should be interpreted with caution.

Studies reveal that different areas of the brain are activated when older and younger adults perform the same lexical access tasks, and similar patterns of activity may yield different behavioral results depending on the age of the individual (Motes et al., 2011; Obler et al. 2010; Reuter-Lorenz, 2002). For example, in verb generation tasks using fMRI, faster-performing older adults showed decreased activity when compared to slower-performing older adults, while faster-performing younger adults showed increased brain activity when compared to slower-performing younger adults (Persson et al., 2004).

In addition to aging, other factors may affect the speed of lexical access. Morphological complexity is one aspect that may logically affect decoding and subsequent retrieval of written words, since words containing bound morphemes contain more linguistic units that must be analyzed by the brain. This may be especially true for verbs; additional morphemes carry information regarding tense and person, which require access of multiple aspects of the linguistic system. Research has shown differences in lexical access related to morphological complexity as early as 170ms post-stimulus. Zweig & Pylkkänen (2009) used a lexical decision task using nouns as stimuli to discover that morphological complexity (based on the number of morphemes a word contains) affects the amount of activation at M170 (amplitude) but has no effect on latency.

A study by Solomyak & Marantz (2010) used MEG to assess the differences in lexical processing based on word stems in multi-morphemic words. Using a lexical decision task, they compared words containing free stems (e.g., "*predict*able"), bound stems (e.g., "*toler*able"), and words with unique stems (which do not exist in other words, e.g., "*vulner*able"). They found that morphological affix frequency affected M170. Data revealed that, for words that contain bound morphemes but do not exist in a stem-only condition, latency of M170 is determined by frequency of the affix. Authors point to this as evidence for morphological analysis at this level in addition to visual processing. It should be noted that the Solomyak & Marantz study did not contain verbs, nor did it contain a condition for a single free morpheme that can be used as a root (e.g., "kick"). Thus, no conclusions can be drawn regarding the difference between nouns and verbs. Because little is known about how the effect of morphology on lexical access relates to aging or how verbs might be affected in contrast to nouns, it is impossible to make clear predictions regarding how all three variables (morphological complexity, aging, and verbs) might interact. Thus, the present study will not investigate these phenomena.

This raises the question of how to best design a task that has the ability to evaluate lexical and phonological access without engaging other linguistic levels, such as semantics. Research shows that lexical decision tasks are best suited to answer these types of questions. In a study by Gold et al. (2007), 16 participants (mean age 24) engaged in a visual lexical decision task in which diffusion tensor imaging was used to identify correlations between fractional anisotropy (FA, a measure of fiber integrity) in white matter and behavioral response times. Researchers found that faster response times were correlated with high fractional anisotropy in the left inferior frontal and parietal regions (areas surrounding the perisylvian language cortex). No links were found in visual input or motor output regions. Because both real and pseudoword reaction times were linked to the same areas of FA (in areas of the brain previously established as related to phonological processing of written words), researchers hypothesized that participants relied more on their phonological systems to determine lexicality than semantic knowledge.

Throughout the last several sections it has become clear that aging has a significant effect on language, impacting lexical access speed, amplitude, and accuracy. As mentioned previously, phonological aspects of lexical access are affected by aging; therefore, a comparison of older and younger adults using a lexical decision task (sensitive to lexical representations) is likely to reveal important differences.

Neuroimaging studies of Nouns vs. Verbs

Most studies of lexical access have used nouns as stimuli. Nouns are important content words, and most are more easily pictured than other word classes, so they lend themselves well to tests of language. However, verbs are also important content words and investigations of verbs may reveal differences in how different words are processed. PET studies of brain activation during lexical retrieval of verbs and nouns show increased areas of activity during access of verbs when compared to access of nouns (Perani et al., 1999; Warburton et al., 1996). A review of PET studies of noun and verb access found that verb stimuli prompted a greater response in the left temporal, parietal, and premotor/prefrontal regions when compared to nouns (Warburton et al., 1996). A study of 14 male adults (ages 22-26 years) in which a lexical decision task was used to elicit PET images of noun and verb access also found that several areas of the brain were more active when responding to verb stimuli than when responding to nouns (Perani et al., 1999). Researchers hypothesize that this increased activation may be due to activation of semantic information automatically associated with verbs. Because increased amounts of linguistic information may be involved with the lexical retrieval of verbs (such as arguments, agents, and implied goal), it is important to examine verbs and nouns separately.

Perhaps the most relevant evidence of important differences between nouns and verbs comes from Xiang and Xiao (2009). This MEG study of lexical access using both nouns and verbs allows for a direct comparison between the two word types. Researchers identified four peaks of activity for both word types, the first three of which were virtually identical with respect to latency, amplitude, and location. However, the fourth peak reflected increased activity in the left posterior temporal lobe in response to nouns while, in response to verbs, the fourth peak reflected activity in the left inferior frontal region. The fourth peaks also differed in amplitude and latency, with the verb M4 occurring at 411ms and the noun M4 occurring at 430ms after stimulus onset. Results seem to indicate that, at later processing stages, the brain utilizes distinct mechanisms to access different grammatical categories. Given the existing wide body of research pertaining to nouns, it is important to now expand the literature to more accurately represent verbs as well.

Summary of Findings

It is clear that aging affects both language and the brain in many ways. The aging brain undergoes a variety of structural changes, including a decrease in grey matter density (Sowell et al., 2003), reduced brain weight (Kemper, 1993), and thinning of the cortical surface (Thambisetty et al., 2010), and functional changes that correspond to different patterns of neural activation (Reuter-Lorenz, 2002; Obler et al., 2010; Motes et al., 2011). Linguistic abilities decline with aging, leading to difficulty defining words, reduced syntactic comprehension, and an increase in word finding difficulties (Botwinick & Storandt, 1974; Davis & Ball, 1989; Obler et al., 1991; Burke et al., 1991). In addition, older adults perform more slowly and less accurately on naming tasks (Morrison et al., 2003; Nicholas et al., 1985; Ramsay et al., 1999). Clearly, lexical access is affected by aging, but the cause of this difficulty remains elusive. Numerous authors suggest that the most likely source is access to the phonological code or lexical representation rather than semantic representations, but as mentioned earlier most of these studies utilize oral production, hence incorporating motor planning for production into a task meant to target access to phonological representations. Other researchers posit that general slowing of cognitive processing is likely cause for linguistic difficulties, as adults become slower at all stages of linguistic tasks. Neuroimaging of lexical access reveals distinct temporo-spatial patterns corresponding to lexical/phonological access (Pylkkänen & Marantz, 2003; Stockall et al., 2004; Solomyak & Marantz, 2009; Papanicolaou et al., 2006) which may indicate specific differences in lexical processing between older and younger adults, the M350 peak in particular. Few studies have examined changes in lexical access with age, or with verbs, leaving significant questions as to the effects of aging on lexical access, and the unique aspects of verbs as stimuli. The present study seeks to explore some of these unanswered questions.

Understanding of word retrieval in normal aging is important to allow differentiation from degenerative conditions associated with aging such as primary progressive aphasia (the first symptom of which is TOT), mild cognitive impairment and semantic dementia. Gaining a clear understanding of the normal progression of aging in terms of linguistic processing can aid clinicians, families, and individuals in identifying abnormal patterns early so that remediation can begin as soon as possible.

Research Questions and Predictions

The primary aim of this study is to examine the effect of age on lexical access of verbs. The second aim is to examine the time course of lexical access in order to delineate between two hypotheses of word retrieval in aging, the impaired lexical access theory and the general slowing theory. In order to answer these research questions, the MEG and behavioral responses will be compared for linguistically unimpaired young (18-30 years) and older (>60 years) participants for a lexical decision task using verbs.

The dependent measures/variables are 1) latency of M170 bilaterally (time between presentation of word and maximum amplitude of M170 peaks, identified from the magnetic field contour maps), 2) latency of M350 in the left hemisphere (Figure 3 illustrates M170 and M350 peaks), 3) overall magnetic energy in the 300-400ms region in a) frontal channels and b) right hemisphere channels, and 4) RT (time between presentation of verb and button press).

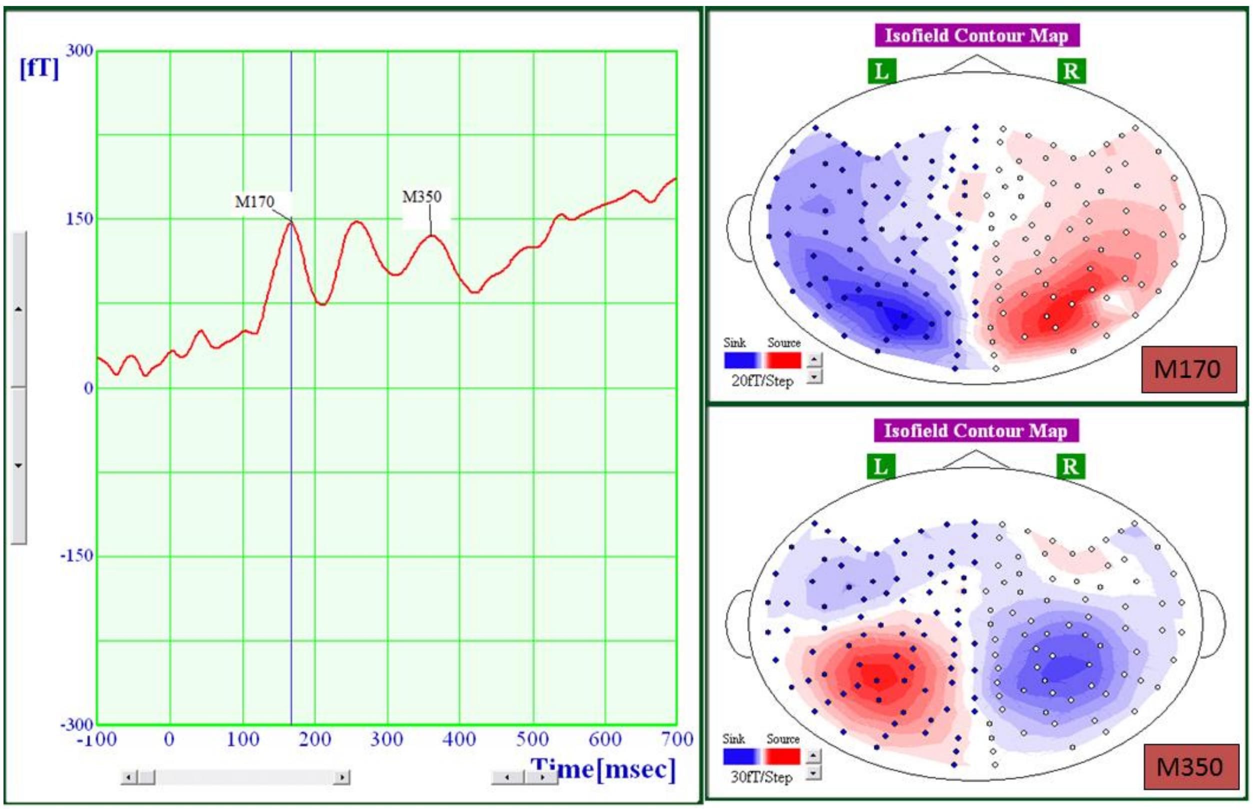

Figure 3. The left side of the image contains the RMS wave form showing amount of dipole activation over time. M170 and M350 peaks are noted. At top right is an isofield contour map showing areas of activation at M170 peak. At bottom right is an isofield

contour map showing areas of activation at M350 peak. Dots on the contour maps indicate placement of one electromagnetic coil.

Because it has been identified as a crucial component of lexical access, examining the M350 peak is key to determining how lexical access is affected by aging. The left hemisphere peak is used in traditional studies since language functions are lateralized to the left; however, because research on aging demonstrates increased activity in the right hemisphere when older adults perform linguistic tasks, data from the right hemisphere during the 300-400ms time window are being included as well. Similarly, studies show increased activity in the frontal regions of older individuals, and a measurement of overall magnetic energy in the 300-400ms range over the frontal and right hemisphere regions will be used to address this finding. Latency of M170 will be investigated in order to test two possible explanations of linguistic changes in aging, reduced ability to access lexical representations and the general slowing hypothesis in which all neurological processing becomes slower. The logic is that if only the M350 is slowed older adults, then it will support a difficulty accessing lexical representations. If both peaks (M170 and M350) are slower in older adults, the general slowing hypothesis will be supported because the M170 is associated with (prelinguistic) orthographic recognition of words.

The following predictions are made for the above dependent variables. We expect to see increased M350 latency in older individuals when compared to the younger group. It is unclear whether or not M170 latency will be similarly increased, but the result will help identify the cause of reduced linguistic performance in older adults. Both the impaired lexical access and global slowing hypothesis predict longer latency in the M350 for older adults for different underlying reasons: a) the mechanisms (and connections between them) that support lexical access (especially phonological representations) have been degraded (due to neurological atrophy and decreased myelination), and b) overall cognitive slowing may result in increased latency in all MEG peaks (M170, M350).

For both right hemisphere and frontal channels, the average and maximum level of activation in 100ms steps (from 0 to 400ms) will be calculated. Increased overall activity is expected to be observed in both right hemisphere and frontal channels in older versus younger participants, because similar results have been demonstrated previously (Obler et al. 2010; Reuter-Lorenz, 2002). We expect increased activity in older adults to correspond with lexical access and therefore be most significant during the 300ms-400ms period. Neither the general slowing theory nor the reduced lexical access hypothesis will be supported by findings of increased activity in the frontal or right hemisphere regions.

It is hypothesized that behavioral lexical decision RT will be delayed in older when compared to young individuals, because past research indicates a variety of changes that cause an overall slowing of linguistic processing as individuals age (including neurological changes (cell atrophy/loss), general cognitive slowing, decreased performance on language measures, and reduced naming abilities (Botwinick & Storandt, 1974; Davis & Ball, 1989, Obler et al., 1991; Burke et al., 1991; Morrison et al., 2003)). RT will not differentiate between the two hypotheses.

Experimental Design

This experiment employs a between-group design. The independent variable is participant age (young vs. old). Dependent variables are behavioral response time, latency and amplitude of M170 bilaterally, latency and amplitude of M350 in the left hemisphere, and total energy during the 300-400ms window in both the right hemisphere and frontal channels.

Methods

Data for this study were previously collected by the Aphasia Research Center at the University of Maryland as part of a larger project on verb processing and neural plasticity in aphasia. It was analyzed post hoc for the purpose of exploring the answers to the above-mentioned research questions.

Participants

Two groups of participants were recruited from the College Park, UMD and neighboring communities. The young adult group consisted of 17 university students (11 female, 6 male, mean age 20.6 years). The older adult group contained 9 individuals (7 female, 2 male, mean age 64.6 years). Participants were screened for right handedness based on the Edinburgh Handedness Inventory (Oldfield, 1971). Self-report was used to verify that participants were English speakers with normal vision and hearing who had no history of speech-language disorders, neurological abnormalities, head injuries, or psychiatric conditions, and no metal implants or dental work that would be sensitive to MEG. Data regarding additional languages spoken, years of education, and occupation were collected as well. Each participant provided informed consent prior to undergoing the experiment and was paid for his or her participation.

Stimuli

The CELEX database (Baayen, Piepenbrock, & Gulikers, 1995) was used to select verbs that had higher verb than noun usage (defined as a verb frequency that exceeded noun frequency by at least 10/million in lemma frequency counts). The verbs were chosen to be mid-frequency verbs, defined as words have lemma frequencies between 50 and 100 per million. Phonotactically legal pseudowords were created by substituting one letter of a verb stem, as in “zide” (from “ride”). Four categories of words were constructed, each containing 50 items. The categories included: uninflected verbs (e.g., “ride”), inflected verbs (e.g., “riding”), pseudoinflected verbs (e.g., “ridest”), and pseudowords (e.g., “zide”). For the purposes of this study, only the inflected verbs were examined. This decision was made based on the available research from which reasonable hypotheses could be formed, as well as to limit extraneous variables in order to obtain as statistically sound results as possible. Inflected verbs contained endings *-s*,*-d*, and *-ing* in roughly equal numbers (17, 17, 16) and could not be confused as noun homophones. Word form frequency (per million) for the inflected verbs ranged from 5 to 13, with a mean of 7.16. Letter length for the inflected verbs ranged from 5 to 10, with a mean of 7.76. One, two, and three syllable words were included. The complete list of stimuli is provided in the Appendix.

Procedure

The experiment consisted of a lexical decision task in which participants viewed words on a screen and provided a two-button press response based on the lexicality of the stimulus item with simultaneous MEG recording. Recording took place in a magnetically-shielded room on the UMD campus. Before entering the MEG scanner, electromagnetic coils were attached to the participant’s head, locations of which were calculated according to three anatomical landmarks (two points just anterior to the ear canals, and the naison). Localization of these coils inside the MEG machine allowed for mapping of MEG measurements onto each participant's individual head coordinate system (see Figure 3 for map of coil placement). In addition, the participants' head shape was traced using an electronic stylus. This was also done to enable orientation of the head within the scanner.

In the MEG scanner, prior to the presentation of experimental stimuli, auditory tones (1kHz) were presented to serve as a calibration method. This is a standard procedure unrelated to the current experiment. However, these tones enable researchers to identify the location of the auditory cortex via an MEG peak that reflects auditory analysis (M100) through dipole source modeling.

For the experimental task, participants were instructed to read the presented words and indicate as quickly and accurately as possible whether the item was a real word (by pushing the left index finger) or a pseudoword (by pushing the left middle finger). Left hand responses were used because this was part of a larger study intended to examine neural activity in aphasia and these participants often have right hemiplegia. Responses using the non-dominant hand can lead to slower and more varied response times; however, because the same procedure was used for all participants it was expected that results would be consistent with respect to one another and not interfere with the validity of statistical analysis. Two hundred stimuli (50 for each condition) were presented on a screen suspended over the participant as he/she lay in the scanner. Each stimulus was displayed for 500ms, and there was an interstimulus interval of 3000ms prior to the next stimulus. No feedback regarding accuracy was provided. The stimuli were presented in a pseudo-randomized sequence ensuring that 1) no two verb roots were repeated ("riding" and “ride”) in consecutive trials 2) the same endings were not presented in consecutive trials, and 3) the same condition (inflected pseudoword, etc.) was not presented consecutively for three trials, using Presentation software version 8.0 (Neurobehavioral Systems). Data was recorded using a 160-channel whole head neuromagnetometer (Kanazawa Institute of Technology, Japan) with a sampling rate of 1kHz and bandpass filtered at 1 to 200Hz. The entire experiment took approximately 20 minutes.

Data Analysis

Because this study is dependent on lexical access, participants with low accuracy, suggesting they were having difficulty with the task, not familiar with the words, or not engaging in lexical access for other reasons, were excluded from the analysis. The data of three younger participants was removed for this reason (accuracy rates of 64%, 52%, and 44%). Because we could not be sure whether the MEG data from these participants accurately reflected lexical access either, both behavioral and MEG data was excluded.

Behavioral data.

During the MEG task, reaction times (RT) to the lexical decision were recorded. Incorrect responses and outliers (RTs that exceed 2.5 standard deviations from the individual’s mean RT or were longer than 3000ms) were excluded from the analysis of RTs.

MEG data.

First, the MEG data were pre-processed to remove unrelated extraneous magnetic activity. The first step, called denoising or noise reduction, was performed in Matlab using the algorithm developed by de Cheveigné & Simon (2007). This procedure also enabled us to identify channels that were sources of excessive noise or were dead due to scanner malfunctions (which occasionally happens). Any noisy channels thus identified were excluded from further analysis. The next step involves sorting responses based on stimulus type and identifying any individual responses that exceed +/- 2.0 pT in amplitude, which were also excluded from the analysis. For each participant, data were averaged according to stimulus type. Baseline correlation was then performed from 100ms pre-stimulus. Low pass filtering was performed at 30Hz.

The resulting data were used to identify the M170 and M350 peaks for each participant. The M170 bilateral peak was determined by selecting 46 posterior sensors (the same for all participants) and identifying peak amplitude and corresponding latency. For nouns, the M350 was defined as a prominent peak in the 300-400ms time range that has a source (P)-sink(N) pattern around the mid-temporal lobe as shown in Figure 2 (Stockall et al., 2004). Because no precedent exists for identifying the M350 peak during visual recognition of verbs (previous studies have used nouns), all sensors in the left hemisphere were included during peak identification (rather than just temporal sensors). To ensure that compounding latency from slower neurological processing did not impact M350 latency measures, M170 latency was subtracted from the M350 peak latency and inter-peak latencies were compared. Computation of MEG responses for lexical access over the entire left hemisphere has been used in other studies (e.g., Monahan, Fiorentino, & Poeppel, 2008). After each peak was identified (manually), its latency (in ms) and amplitude (in femtoTesla-fT) was noted. Since this was manually computed, all peaks were also independently identified by another trained scorer (Dr. Faroqi-Shah) for the purposes of reliability. The M170s and M350s obtained by the two scorers were compared for consistency. Any discrepancies were resolved by discussion and consensus.

Initial agreement for peak amplitudes and latencies was 82%. Once amplitude and latency had been determined for each participant, Mann-Whitney U-tests were used to compare the data between young and elderly groups to determine the effects of aging.

In order to compute the magnetic energy over the frontal sensors (bilaterally), the frontal sensors were selected based on a sensor template used in 10-20 system (Jasper, 1958) as illustrated in Figure 4. Average energy and peak energy during each 100ms time window (0-100, 100-200, 200-300, and 300-400) were noted in the MEG 160 program. The same procedure was used to identify activity in the right hemisphere as well.

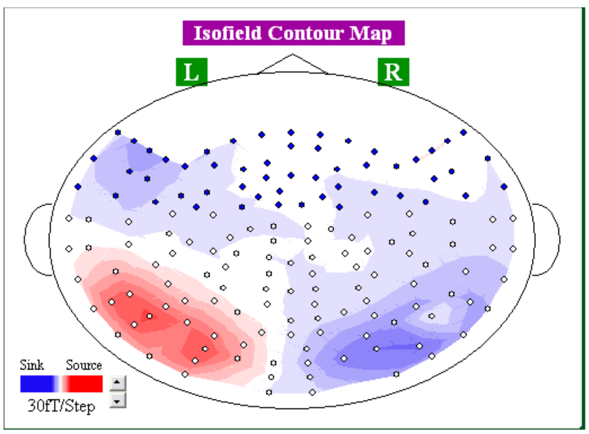

Figure 4. Sensors included in analysis of frontal neural activity.

Finally, an exploratory post hoc analysis of male vs. female participants was conducted to identify any interaction between gender and aging. This analysis was performed based on research that shows male and female brains are affected differently by aging, with grey matter volume decreasing more significantly in aging males than in aging females (Good et al., 2001). However, another study found that while females did perform better on certain language measures, there was no interaction between age and gender (Snitz, Unverzagt, Chang, Bilt, Gao, Saxton, Hall, & Ganquli, 2009).

Furthermore, it has been shown that males have more difficulty recognizing spoken words as they age, while females do not (Dubno, Lees, Matthews, & Mills, 1997).

All statistical comparisons between two groups of participants were made using a Mann-Whitney U-test at two-tailed p=.05. Prior to statistical analysis, a Shapiro-Wilk test was performed on all data to test for normal distribution. Although some data sets are normally distributed, the majority is not and therefore must be examined using non-parametric methods. For the sake of continuity, a Mann-Whitney U-test was performed on all data sets. When appropriate, T-tests were used in addition, the results of which are noted (see tables 1, 2, and 3).

Results

Behavioral Data

Accuracy.

Due to technical error, the accuracy and response time data for 4 of the young participants was not available. In addition, one participant's accuracy data were incomplete (data from the last block-25% of data) due to an error in recording; therefore, the accuracy for that individual was obtained for 35 items only. Since there were 50 stimulus items, accuracy is given out of a possible 50. The mean accuracy for older participants (N=9) was 48.00 (SD=1.58) and was 45.33 (SD=4.89) for the younger participants (N=10). Table 1 provides the data for behavioral measures. The difference approached but did not attain statistical significance (Mann-Whitney U=29.0, z=-1.635, p=.172). These results approach significance, but in an unexpected direction, with the younger adults performing less accurately than the older adults.

Response time.

Behavioral response times (RT) were recorded for all participants. The mean RT for older adults was 1241ms (SD = 442.32) and 964ms (SD = 426.11) for younger participants. The younger group was significantly faster than the older group (Mann-Whitney U=39368.00, z = -12.99, p <.001).

	Group Mean (SD)		P value (Mann-Whitney U)	T-Test P value
Measure	Young	Older		
Behavioral Accuracy (max=50)	45.33 (4.89) N=10	48.00 (1.58) N=9	.172 (29.00)	N/A
Behavioral RT (ms)	964.20 (426.11) N=10	1241.15 (443.20) N=9	<.001 (39368.00)	N/A
M170 Latency (ms)	138.77 (11.18) N=10	141.50 (17.06) N=8	.593 (34.00)	.385
M170 Amplitude (fT)	85.19 (38.07) N=10	107.15 (46.91) N=8	.424 (31.00)	.445
M350 Latency (ms)	333.23 (27.42) N=10	333.75 (17.84) N=8	.099 (21.50)	N/A
M350 Amplitude (fT)	64.30 (17.63) N=10	65.78 (18.31) N=8	.594 (34.00)	.580

Table 1. Behavioral and MEG peak data.

MEG data.

For peak analysis, the MEG data for 1 older individual demonstrated unusual neurological activity and contained ambiguous M170 and M350 peaks (no change over time in neuromagnetic pattern was observed, which could have been due to head positioning in the scanner or cortical topography since MEG only detects source-sink that is perpendicular to the surface of the skull), and were therefore excluded from peak analysis. Data from this participant were included in analysis of total energy in the right hemisphere and frontal lobe, since such analysis does not rely on information provided by peaks.[1] Table 1 describes the MEG data and significance.

M170.

The mean M170 latency for older participants (N=8) was 148.2ms (SD=25.72) and was 143.29ms (SD=28.33) for the younger participants (N=13). There was no significant difference between groups for latency (Mann-Whitney U=34.00, z=-.534, p=.593). The mean M170 amplitude for the older adult group was 104.69 fT (SD = 44.49) and was 89.60 fT (SD= 34.38) for the younger adult group. There was no significant difference between groups for amplitude (Mann-Whitney U=31.0, z = -.800, p = .424).

M350.

The mean M350 latency for older participants (N = 8) was 327.25ms (SD = 10.85) and 338.13ms (SD = 32.73) for younger participants (n = 13). There was no significant difference between groups for latency (Mann-Whitney U=21.50, z = -1.651, p = .099). The mean M350 amplitude for the older adult group was 79.13 fT (SD = 38.36) and was 74.80 fT (SD = 27.25) for the younger group. There was no significant difference between the groups for latency (Mann-Whitney U=34.0, z = -.533, p = .594).

[1] Statistical analysis of right hemisphere and frontal sensor energy was also performed with the data from participants with ambiguous peaks removed, without significant change in the results.

Right Hemisphere.

Total energy and maximum energy in the right hemisphere of each participant was calculated for time windows 0-100ms, 100-200ms, 200-300ms, and 300-400ms. For both right hemisphere and frontal lobe analyses, all participants were included. It was not deemed necessary to exclude those for whom M170 or M350 peaks could not be reliably identified because total energy (not peaks) were being examined in areas of the brain besides the left hemisphere. A comparison between the amount of activity in the right hemispheres of younger and older participants during the 300-400ms window, which correlates with lexical access, revealed no significant differences. Table 2 contains a full description of MEG data and significance.

Right Hemisphere	Group Mean (SD)		P value (Mann-Whitney U)	T-Test P value
Time Period	Young N=17	Older N=9		
0-100ms Average	51.09 (10.79)	57.15 (15.74)	.208 (43.00)	.221
0-100ms Maximum	121.01 (39.15)	130.79 (43.49)	.413 (50.00)	.440
100-200ms Average	86.20 (23.00)	103.74 (32.74)	.147 (40.00)	.133
100-200ms Maximum	210.93 (66.71)	244.30 (110.12)	.313 (47.00)	.288
200-300ms Average	66.95 (21.86)	68.82 (26.48)	>.999 (63.00)	.899
200-300ms Maximum	157.12 (56.24)	159.24 (75.91)	>.999 (63.00)	.766
300-400ms Average	51.03 (16.55)	48.49 (16.51)	.614 (55.00)	N/A
300-400ms Maximum	109.15 (39.15)	113.81 (41.50)	.450 (51.00)	N/A

Table 2. MEG data for right hemisphere neuroenergy and Mann-Whitney U results.

Frontal sensors.

Total energy and maximum energy in the frontal lobe of each participant was calculated for time windows 0-100ms, 100-200ms, 200-300ms, and 300-400ms. A comparison between the amount of activity in the frontal sensors in younger and older participants during the 300-400ms window, which correlates with lexical access, revealed no significant differences. Table 3 contains a full description of MEG data and significance.

Frontal Sensors	Group Mean (SD)		P value (Mann-Whitney U)	T-Test P value
Time Period	Young N=17	Older N=9		
0-100ms Average	40.26 (8.50)	47.61 (19.69)	.659 (56.00)	N/A
0-100ms Maximum	88.84 (70.07)	91.72 (42.37)	.705 (57.00)	N/A
100-200ms Average	61.84 (17.65)	69.93 (28.66)	.705 (57.00)	N/A
100-200ms Maximum	125.43 (42.10)	147.21 (65.43)	.659 (56.00)	N/A
200-300ms Average	60.11 (25.46)	71.52 (39.00)	.801 (59.00)	N/A
200-300ms Maximum	132.61 (61.66)	126.60 (57.59)	.659 (56.00)	N/A
300-400ms Average	51.69 (13.30)	45.15 (15.98)	.257 (45.00)	.316
300-400ms Maximum	117.16 (45.91)	104.58 (33.52)	.659 (56.00)	N/A

Table 3. MEG data for frontal channels neuroenergy and Mann-Whitney U results.

Gender.

Data were also analyzed according to gender, in order to explore the differences between the effects of aging on lexical access of males vs. females. No significant interaction of gender was found; however, this analysis was limited by the small number of male participants.

Discussion

This study is the first, to our knowledge, to explore age effects in lexical access using MEG. The primary aim of this study was to examine the effect of age on lexical access of verbs. Based on prior research on lexical access, it was predicted that older adults would demonstrate increased latencies (reflected both in behavioral response time and M350) when presented with visual word stimuli than younger adults. The study found that, while behavioral RTs for lexical decision were significantly slower for older adults, there were no significant differences in MEG responses between young and older groups. The second aim of this study was to examine the time course of lexical access in order to delineate between two hypotheses of word retrieval in aging, the impaired lexical access theory and the general slowing theory. We anticipated the possibility of differences in M170 latencies, which could be used as evidence supporting either the general slowing hypothesis (if increased M170 latency was observed in the older group) or the idea that older adults have reduced access to lexical representations (if no M170 differences were seen). The data showed no significant differences in M170 latencies. In addition, we expected to see between-group differences in total activation of the right hemisphere and frontal cortex based on prior neuroimaging findings that showed altered lateralization and frontal activity in older adults. This prediction was not supported by the results. The implications of these findings are discussed in the following sections.

Behavioral RT.

The only significant finding in our study was that older adults had a significantly slower behavioral response time than younger adults. This was expected, and is consistent with other findings that older adults are slower at lexical decision tasks with nouns (Bowles & Poon, 1981; Moberg, Ferraro, & Petros, 2000; Taler & Jarema, 2007) and verbs (Kavé & Levy, 2005), as well as picture naming tasks (Moberg et al., 2000; Morrison et al., 2003; Nicholas et al., 1985; Ramsay et al, 1999). The slower RT could be due to a number of factors, including orthographic processing, aspects of lexical access not identified by MEG, or slowed motor response time. It could also be that older adults are simply more likely to reflect on the accuracy of their decision before pressing the button than younger individuals are. Deliberate decision making might be the best explanation for the slowed response time, since the simple decision task showed quite a significant delay with aging (almost 280ms) while demonstrating intact lexical processing.

Accuracy.

Accuracy data showed no significant difference between younger and older participants. This is not entirely unexpected, and is consistent with prior research of single-word responses (Moberg et al., 2000). Although some studies do demonstrate reduced accuracy with aging, older adults are typically able to respond correctly at least 90% of the time (Ramsay et al, 1999).

MEG responses.

As mentioned earlier, we found no significant differences in amplitude or latency for either the M170 or M350 peaks, or in amount of activity in the right hemisphere or frontal region of the brain when comparing the older and younger groups. This is contrary to what is predicted by many other studies; however, most previous research has utilized different methods than we have employed and may logically yield different results. The various explanations for lack of group differences are discussed here.

The work of Bowles & Poon (1981) may be most similar to ours, in that they utilized lexical decision of verbs, and our results are consistent with conclusions they drew, namely that decreased performance with aging is due to sensorimotor deficits more than impaired lexical access. In addition to a lexical access task, their study incorporated a button press reaction time task which did not involve lexical access. Even when removing the variable of lexical access, older adults performed significantly more slowly. Although our study did not have a similar control task, our results (apparently unimpaired lexical access with significantly increased response time) are consistent with theirs and would support the idea that sensorimotor function is impaired in aging rather than lexical access. Alternatively, it could be argued that lexical decision tasks do not require access to phonological encoding, which is typically more impaired in older adults than semantic access (Burke & Shafto, 2004). Older adults' experience of TOT may be more closely related to phonological access and motor output than to access of lexical representations.

The present study used a lexical decision task, which relied on an individual's ability to recognize a written word. Many previous studies used picture naming tasks, which challenge the participant to think of and produce a word expressively, rather than recognize it receptively. This may be a more difficult task, and indeed, TOT phenomena are documented both by research and anecdotally (Burke et al., 1991), indicating that word finding becomes more difficult with age. Furthermore, much of the evidence supporting decreasing language abilities in older adults illustrates difficulty performing complex language tasks such as discourse production (Kynette & Kemper, 1986) or comprehension of complex syntax (Davis & Ball, 1989; Obler et al., 1991). In fact, past studies have shown that while older adults do have difficulty completing word retrieval tasks, they do not show similar difficulties in word recognition tasks (Burke, MacKay, & James, 1999).

It is likely that receptive language skills remain fairly intact as individuals age, and that older adults are able to perform simple tasks such as single-word recognition without difficulty. However, when demands on the system increase, as with comprehension of complex syntax, the slight reduction in linguistic ability becomes more significant and older adults are unable to perform as well. This would suggest that representations themselves remain intact; however, rapid connections between them, which are required for speech production, are weakened, most likely due to demyelination.

Because we did not find a significant difference in lexical access at a neurological level, this study does not provide sufficient evidence to differentiate between the general slowing theory (Myerson et al., 1992) and the impaired lexical access hypothesis (Burke & Shafto, 2004). It is also not clear if other theories such as the reduced inhibition theory (Sommers, 1996), or the diminished-resource hypothesis (Craik & Byrd, 1982) can account for the lack of MEG differences.

The most conservative interpretation of the results is that slower RT output observed in older adults is caused not by reduced speed of lexical access, but in a later stage of language processing. A breakdown may occur in the transport of lexical information to the motor planning areas, or in the motor execution itself, or in selecting the appropriate response (finger to press). This idea is supported by the work of Burke & Shafto (2004), who demonstrated that phonological access (which occurs after the lexeme is accessed) is generally more severely impaired in older adults than semantic access.

Although the difference was not statistically significant, we found that the younger group was less accurate to distinguish between real words and non-words. This was somewhat unexpected based on previous research, which points to equal or poorer language skills in older adults in virtually all measures (Botwinick & Storandt, 1974; Burke et al., 1991; Davis & Ball, 1989; Kynette & Kemper, 1986; Nicholas et al, 1985; Ramsay et al., 1999; Obler et al., 1991). However, many of these studies used more complex tasks which put a greater strain on the language system than the present study. Specific aspects of the current task may have taken advantage of relative strengths in older adults. For example, a meta-analysis of aging and vocabulary skills showed that overall older adults have better vocabularies than younger adults (Verhaeghen, 2003), which is a benefit in a word recognition task. Because our study used fairly common words, there may have been a long-term “priming” effect in which the older adults were able to rely on years of increased exposure to the written stimuli, while the younger adults had fewer experiences with the words and therefore did not recognize them as automatically. Morrison et al. (2003) found that word frequency had a much more significant effect on the accuracy and latency of older adults than younger adults during a naming task, while Newman & German (2005) found that familiarity of the word played an important role in the performance of older adults. Almor et al. (2005) found similar frequency effects with respect to reading verbs. This may point to more efficient organization of the mental lexicon with age, with frequently encountered words being more easily accessible than words that are less likely to be used. Greater differences may be found in an experiment similar to ours utilizing a wider range of frequent and less frequent verbs. In addition, the younger adults may simply have been more distracted during the task.

To conclude, the present study found strong evidence for slower lexical decision response times in older adults compared to young adults. However, no significant differences in MEG responses were noted. This could either mean that there are no differences in input until the word recognition stage, or that the MEG measures used in this study were not sensitive to the neural changes that occur with aging.

Directions for future research

More research needs to be done in order to provide further insight into how aging affects the lexical access of verbs. The present study inherently contained a number of limitations. Significant amounts of information were lost due to technical error and low accuracy rates of younger participants. This may indicate that the younger participants would benefit from either more precise instructions, or reminders throughout the task regarding which button to press. In addition, imposing more phonological control over the stimulus items would have allowed for comparisons between phonological variables. This could have provided some insight into the role of phonological processing/decoding on lexical access.

Future studies could include picture naming or even more complex tasks such as narrative generation as well as MEG data in order to compare MEG response with naming or other language abilities. This would enable researchers to correlate neurological patterns more closely with real-world language performance. In addition, in a future study it would be beneficial to include a button press control task to account for differences in motor response. Most importantly, because our data seem to imply that the language processing changes that occur with aging affect a later stage than lexical access, research into the phonological encoding process should be done. Comparing the phonological encoding or retrieval skills of older and younger adults could reveal important differences that may lead to a better understanding of how aging affects language processing, and possibly one day to more effective treatment of age-related decline.

Appendix

Stimulus	Lemma frequency (per million)	Word form frequency (per million)	Letter length
admits	97	7	6
admitting	97	5	9
arranging	88	9	9
claimed	100	6	7
climbed	92	7	7
combining	66	6	9
cooked	72	6	6
counts	63	7	6
denying	65	9	7
dividing	64	8	8
emerges	80	8	7
employed	62	8	8
employing	62	6	9
employs	62	5	7
gathered	76	8	8
ignores	70	5	7
improved	94	8	8
insisted	78	8	8
insists	78	8	7
intends	79	5	7
inviting	65	6	8
lifted	88	6	6
lifts	88	5	5
locked	62	6	6
locking	62	5	7
maintains	95	6	9
nodding	79	9	7
obtaining	67	8	9
performed	78	9	9
poured	79	6	6
prefers	82	5	7
prevents	93	6	8
proposing	63	6	9
protecting	86	10	10
reflecting	78	8	10
reflects	78	13	8
repeated	66	8	8
replacing	75	8	9
revealing	79	8	9
reveals	79	9	7
settled	80	7	7

shouted	84	7	7
stretched	67	9	9
succeeding	66	6	10
succeeds	66	5	8
survived	89	8	8
survives	89	7	8
threatens	63	6	9
treated	98	7	7
treating	98	10	8

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