AN ELECTROPHYSIOLOGICAL INVESTIGATION OF THE EFFECTS OF AGE ON THE TIME COURSE OF SEGMENTAL AND SYLLABIC ENCODING DURING IMPLICIT PICTURE NAMING IN HEALTHY YOUNGER AND OLDER ADULTS

By

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Abstract

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Yael Neumann

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Lexical access models for speech production generally include three processing stages, namely, retrieval of conceptual-semantic, syntactic, and phonological information. Neuroimaging studies have examined the time-course of these stages in young adults. However, there is scant research investigating the time-course of the various phonological substages in younger, and particularly in older, adults.

This study made two comparisons in healthy younger and older adults: 1) a between-subjects comparison of the effects of age on the phonological retrieval process, and 2) a within-subjects comparison of the time-course of the phonological substages, segments vs. syllables. The ERP component N200, reflecting response inhibition, was elicited using a Go/Nogo paradigm with implicit picture naming. Additionally, P300 and Visual Evoked Potential (VEP) components were investigated to account for cognitive effort and sensory processing contributions to performance.

Results support the Transmission Deficit Hypothesis (Burke et al., 1991) of age effects at the phonological level, as N200 latencies on both phonological tasks were later (100 ms) in the older, as compared to the younger, group. In particular, within the older group, retrieval of syllabic information was significantly later (50 ms), as compared to retrieval of segmental information. These findings further suggest that the phonological breakdown is greater at the syllabic, than segmental, level.

Additionally, P300 and VEP results revealed no significant latency delays between groups and on both tasks. Thus, the data suggests that phonological processing delays in the older group were neither due to cognitive nor early visual processing delays, but rather to stage-specific phonological processing deficits. However, group differences in amplitude of the P300 on the segment task, and VEPs (at 201-250 ms) on both tasks, were seen. These findings suggest that with age greater cognitive effort was needed to perform the segment task, and greater visual attention was expended on both tasks.

Lastly, results support the parallel view of processing for segmental and syllabic phonological substages, although in the older adults the data showed that syllabic access is affected more than segmental access.

Implications of the study are that healthy older adults might benefit from practice with phonological tasks, mainly of syllabic information, to improve retrieval.

DEDICATION

I dedicate this dissertation to my dear mother, Pnina Neumann, to whom I owe everything. She is a constant wellspring of inspiration and encouragement, an unwavering cedar tree of support, and my #1 cheerleader. All that I have achieved is to her credit.

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Chapter 1: Introduction

1.1 Overview

The ability to speak, from concept formation to articulation, is what makes us uniquely human. Amazingly, this complex capability occurs automatically, efficiently and without much conscious effort. Attention to the multipart processes underlying lexical retrieval is often taken for granted until there are breakdowns in production. Early neurolinguistic studies capitalized on such errors in speech production as a ‘window’ into understanding the normal process of lexical retrieval (Brown and McNeill, 1966; Butterworth, 1989; Fromkin, 1973; Garrett, 1988, 1993). Everyday speech errors were initially the prime means of understanding how subprocesses in production proceed. More recently, neuroimaging techniques (e.g. electrophysiology and magnetoencephalography (MEG)) which are capable of examining neural processing in split-second precision, have also contributed to the refinement of this understanding (Indefrey and Levelt, 2004; van Turennout, Hagoort and Brown, 1998).

Currently, the literature is in general agreement that lexical access for speech production involves retrieval of three different types of information namely, conceptual-semantic, syntactic, and phonological information, in at least two distinct processing stages (Dell and O’Seaghdha, 1992; Levelt, 1989; Levelt, Roelofs and Meyer, 1999). The function of the first stage is to select an abstract representation of the target lexical item containing only semantic and syntactic information, and the function of the second stage is to phonologically encode the chosen lexical item in preparation for articulation.

Research on language production in older adults with unimpaired cognitive abilities suggests that the naming problems associated with advanced age arise in, or just before, the second, phonological stage. Therefore, the present study focused on the second stage of phonological encoding in an attempt to answer two questions. First, **how does age affect retrieval of segments (phonemes) and syllables in a picture naming task?** And, second, **what is the time course of retrieval of these specific phonological substages? Do these substages proceed in parallel or serial fashion?**

This chapter will begin with an overview of behavioral findings on aging and lexical access problems. Then, an outline of the three processing levels involved in speech production will be described, according to the Levelt et al. (1999) model, followed by a summary of findings from time course studies of speech production, with a particular focus on the phonological encoding stage. Lastly, a general review of aging effects on electrophysiological components will be presented, leading into the research questions and hypotheses for the present study.

1.2. Lexical Access Problems in Healthy Adults

A common complaint among healthy individuals as they age is the increased frequency of word-finding problems in their everyday speech. This phenomenon, colloquially described as a tip-of-the-tongue (TOT) state, is often accompanied with a feeling-of-knowing (FOK) such that individuals may know what they want to say but some or all of the phonological information of the word is temporarily unavailable. Furthermore, they are able to reject any incorrect alternatives as they struggle to produce the target word.

Brown and McNeill (1966, p. 325) best described a TOT state as “a failure to recall a word of which one has knowledge”. Thus, individuals experiencing this type of word-retrieval failure are able to access the conceptual, semantic, syntactic and even some phonological/orthographic information of the target word, however, not enough to fully phonologically encode the word for production.

Various theories as to why there are lexical access difficulties have been proposed. The Node Structure Theory (NST; Mackay, 1987) is one well-accepted account explaining that TOT breakdowns are due to insufficient priming of the connections between conceptual/lexical and phonological nodes. The Transmission Deficit Hypothesis (TDH; Burke, Mackay, Worthley, and Wade, 1991; James and Burke, 2000; MacKay and Burke, 1990) is another theory which similarly proposed that TOTs are due to a failure in the transmission of available semantic/syntactic information to the phonological system. However, the TDH also furthered the NST in defining the role of aging within the model. Burke et al., (1991) explained that older people are especially prone to word-retrieval problems due to weakening of lexical-phonological connections in memory. Evidence from a variety of priming studies has demonstrated strong support for both these theories (Abrams, White, Eitel, 2003; Burke, MacKay, Worthley and Wade, 1991; Cross and Burke, 2004; Heine, Ober, and Shenaut, 1999; James and Burke, 2000; Rastle and Burke, 1996; White and Abrams, 2002).

But why are phonological features at the phonological level more vulnerable to retrieval breakdowns than semantic-syntactic features at the conceptual/lexical level? The reasoning is that the phonological level generally has fewer connections (e.g. phoneme-sound), whereas the lexical-semantic system has multiple connections (e.g. many words/concepts linked to a given word) (James and Burke, 2000; MacKay and Abrams, 1996). Aging weakens the links in the system, in particular, affecting the most vulnerable links. Factors such as word frequency or recency of use influence the strength of phonological connections and thus retrieval of those elements. Therefore, the lower the word frequency and the less recently used, the weaker the connections and the greater the difficulties in retrieving it.

In a pivotal study by James and Burke (2000), a two-part experiment was conducted to evaluate TOT states in both younger and older individuals. In the first experiment, prime words were either phonologically-related or unrelated to the low-frequency targeted single-word response. These prime words were presented on a computer screen and participants were asked to say the word aloud and then rate how difficult it was to pronounce. This latter rating task was included only to disguise the relation between the prime and target, thereby minimizing the influence of a conscious retrieval process, as was the problem with Meyer and Bock (1992). This was important so that findings would reflect automatic processes rather than directed memory strategies, e.g. consciously searching for the word with similar phonological properties of the cue, in the process of retrieval during a TOT state.

In the second part of the James and Burke experiment, participants were asked general-knowledge questions which required them to retrieve proper names and seldom-used words, to induce a TOT state. Then they were asked to provide the target word. If participants experienced a TOT state, ten phonologically-related or ten phonologically-unrelated prime words appeared on the screen, which they had to pronounce aloud, before again being prompted to answer the question. Both younger and older adults benefited from phonological primes as opposed to unrelated primes during moments of a TOT state. These phonological cues were hypothesized to strengthen the weak phonological connections and thus facilitate resolution of the TOT state. The practical application of these findings, the authors argued, is ‘use-it-or-lose-it’. Older individuals should continue to use and be exposed to words, e.g. via reading, crossword puzzles, and meaningful conversation, as they age, to maintain strong phonological connections (Schooler, 2007, Peters et al., 2007; for opposing view see Salthouse, 2007).

In contrast to the finding that phonological cueing facilitates resolution of TOT states, the Blocking/Inhibition theory proposed that phonologically similar words inhibited resolution of these states (Woodworth (1929) as cited in Jones (1989) and Perfect and Hanley (1992). This earlier theory arose from models highlighting inhibitory processes (e.g., Stemberger, 1985). Experimental support for this view was demonstrated in a definition task of rare words (Jones and Langford, 1987; Jones, 1989). TOT-inducing questions were followed by an alternate word that was related in one of four ways to the answer: phonologically, semantically, phonologically and semantically, or unrelated. These alternate words were controlled for frequency rate.

Jones and Langford (1987) and Jones (1989) found that only in the phonologically related condition did the alternate words promote more TOT states and inhibit word-retrieval in young adults. This study was replicated in an older adult population aged 52-78 years (Maylor, 1990), and findings similarly supported the blocking theory as participants experienced more TOTs in the phonological condition.

However, these conclusions were short-lived as other studies found that Jones did not control task set-up adequately. Meyer and Bock (1992) and Perfect and Hanley

(1992) reported that the general knowledge questions evoked more TOT states and more of this type of question were associated with the phonologically related than semantically related condition. Thus, the hypothesis of the Blocking/Inhibition theory that phonological blockers would inhibit retrieval thereby increasing TOTs was discredited.

In sum, research of TOT states in the aged population supports the TDH model (Burke et al., 1991; Cross and Burke, 2004; Rastle and Burke, 1996; White and Abrams, 2002) pointing to a breakdown at the phonological encoding level. However, due to limitations of behavioral methods in investigating the precise nature of the phonological processing problem, the locus of the breakdown in access within the phonological level is unknown.

1.3. Models of Lexical Access for Speech Production

Consider what happens when a person is shown a picture of "horses". In the milliseconds prior to naming, research suggests that the process of lexical retrieval can be viewed as proceeding in a two-stage manner (Figure 1). During the first stage, the person recognizes the picture, which activates multiple lexical concepts (e.g. [horses], [animals], etc.). Selection of the target lexical concept depends on one's communicative intention and perspective, or on the specified experimental task. For example, for a categorization task the person may select the superordinate concept [animals] and for a standard naming task the person may select the concept [horses]. These multiple concepts spread their activation to their unique lemma, i.e., the semantic and syntactic description of the lexical item. For example, the concept [horses] will activate the semantic attributes, such as, 'has a tail', 'mane', 'neighs', and syntactic elements (e.g. plural, noun, etc.). The various lexical items that are similar in description compete for activation until the end result is the selection of one and only one lemma with the greatest activation (Levelt et al., 1999).

During the second stage of processing, the target lemma is phonologically encoded into a lexeme, which is an abstract representation of the phonological specifications of the lexical item. First, the segmental and metrical frame is created. This involves retrieval of morphemic and phonological codes, such that individual phonemes or ‘segments’ (e.g. /h/ />/ /r/ /s/ /I/ /z/) are ordered and spelled out. As well, the metrical structure or ‘frame’ of the target word is created, including the number of syllables and location of stress (e.g. /h>rsIz/ has two syllables and initial syllable stress). The segments are inserted into the lexeme’s frame to construct a phonological word frame (e.g. [h>r]’ [sIz], initial syllable stress). This is known as ‘segment-to-frame association’.

According to Levelt et al. (1999), this process of segmental and metrical retrieval occurs in parallel fashion although encoding is assumed to occur incrementally from left to right. Evidence for the sequential nature of these processes arises from a study by Meyer (1990). In his experiment, the time course of phonological encoding, specifically, at the syllabic level, was investigated. Bi- and tri-syllabic words were primed by either the first, second, or third syllable and facilitatory effects were measured in the time it took the participant to produce the response word. Results revealed that the facilitatory effect of priming was influenced by which syllable was primed. Namely, in bi-syllabic words only first, not second, syllables facilitated naming, and in tri-syllabic words the second syllable facilitated production only if the first syllable was already known. These findings thus point to the view of a strictly sequential process in syllable encoding.

At times syllabification of the word during this process may run over morpheme and lexical boundaries depending on the co-articulatory influences of the given context. Thus, syllabification of the word depends on the given context and is not stored in the mental lexicon, e.g. /h>r/ is a syllable of “horses” but not of “horse”, while /h>rs/ is a syllable of “horse” but not of “horses” (Wheeldon and Levelt, 1995; Meyer, 1990).

The final substage within phonological processing for naming is retrieval of the syllabic gestural codes from the mental syllabary, an abstract store of highly-practiced phonetic syllables. These phonetic codes are understood and accomplished by the articulatory apparatus, resulting in articulation or overt speech.

1.4. Electrophysiological Evidence of the Time Course of Speech Processes

It is only within the past decade that researchers have begun to use the dynamic measure of real-time activation of event-related potentials (ERPs) and other imaging techniques, to detect the temporal processing of distinct types of word information in speech production (see Indefrey and Levelt, 2004 for a meta-analytic review of imaging literature on word production). Most studies have used evoked cortical responses such as the lateralized readiness potential (LRP) and/or N200 to assess the points in time when different types of lexical information are retrieved for speech production.

The standard task employed is picture-naming as it is assumed that this task requires the speaker to activate the complete process, both selection and encoding of a specific concept in the word-retrieval process (Glaser, 1992). The LRP indexes response preparation (for example, getting ready to press a button). It is obtained over the motor cortex (C3, C4) contralateral to the response hand. The N200 indexes response inhibition (for example, withholding a button-press response). It is seen as a large negative peak occurring between 100-300 ms over frontocentral scalp sites.

Van Turennout, Hagoort and Brown (1997), were forerunners in applying the Go/Nogo paradigm with ERP methodology, to test predictions of speech production models. A two-choice Go/Nogo classification task was used to elicit the LRP. In this paradigm, participants were asked to categorize picture names along a semantic-conceptual domain (animate vs. inanimate) and a phonological domain (final phonemes /n/ vs. /r/). The electrophysiological component of interest was the LRP which is detected before or even in the absence of an overt button-press response but only when enough information is available in the brain for a decision to be made. This motor-related brain activity is assumed to reflect an upper limit on the moment in time when a Go (press the button) or Nogo (do not press the button) decision, based on either phonological or semantic information, must be available.

There were two versions of this task which were administered to all participants. In one version, the phonological classification determined whether a response was to be given (phonology=Go/Nogo) while the semantic classification determined the response hand (semantic=right hand vs. left hand). It was predicted that for this set-up an LRP would be obtained on both Go and Nogo trials. The reasoning is that semantic processing is expected to precede phonological processing, thus response preparation will occur initially even on Nogo trials as phonological information would not yet be available to overrule response preparation. It is only once phonological processing has begun that the preparation for one hand will be terminated as the participant has enough information to know to withhold a response. In this case, the corresponding LRP will fall back to baseline.

The second version of the study was constructed in order to ascertain that LRP results from the first task were really due to retrieval differences, namely that semantic processes precede phonological processes, and not to task arrangement, namely that response hand selection necessarily precedes the Go/Nogo decision. Thus in the second experiment, the task conditions were switched such that now semantic classification determined whether a response should be given (semantic=Go/Nogo) and phonological information determined the response hand (phonology=right hand vs. left hand). It was predicted that an LRP would be obtained only for Go trials as response preparation was dependent on semantic processing which is expected to occur prior to phonological processing regardless of task configuration.

The findings of van Turennout et al. (1997) confirmed these predictions. In both experiments the onset of the LRP waves was analyzed to reflect the point in time when processing for the phonological or semantic information had begun. In version #1, Go and Nogo waves were significantly different from baseline but not from each other at around 370 ms and 380 ms, respectively. This finding reflects the point in time at which semantic information was retrieved although phonological information was not yet retrieved. The overlap of Go and Nogo waves was maintained for 120 ms and diverged at 590 ms when the Nogo wave slowly returned to baseline and was not significantly different from baseline. At 490 ms the Go wave continued to develop reaching a maximum amplitude at 840 ms, and was significantly different from the Nogo wave, reflecting when phonological information was retrieved. The presence of the LRP on

Nogo trials at 370 ms post picture onset demonstrated that preparation for a semantic response started before phonological processing and was available to indicate a Nogo trial. At 490 ms the Go and Nogo responses diverged indicating that phonological information was now available.

In the second task, there were no significant LRPs on the semantic Nogo trials, however, on semantic Go trials the Go wave was significantly different from baseline and started to diverge from Nogo waves at 410 ms and reached maximum amplitude at 820 ms. This finding substantiated the conclusion from the first experiment that regardless of task configuration the time course of semantic processing preceded that of phonological processing.

Yet, a third experiment was devised to provide insight into how the time course for full phonological encoding for speech production proceeds. A focus on retrieval of semantic information to word-initial, as opposed to the prior experiments word-final, phonological information, was performed (van Turennout et al., 1997). The task required participants to make a Go/Nogo decision regarding the initial phoneme of the word, while keeping the hand-choice decision based on semantic classification. Results demonstrated that Go waves were significantly different from baseline at 360 ms, reflecting when semantic information was available, and reached maximum amplitude at 780 ms; while Nogo waves diverged from Go waves at 400 ms, demonstrating the point in time when initial phonological information was available.

Taken together, these results revealed that semantic information is retrieved approximately 40 ms prior to initial-word-position phonological information and approximately 120 ms prior to final-phoneme encoding. When comparing the length of time for the Nogo LRP in word initial vs. word final phoneme conditions, it was estimated that it takes about 80 ms longer to encode word-final than word-initial form for words with an average of 4.5 phonemes. Thus the complete process of phonological encoding following retrieval of semantic information to the spell-out of the final phoneme in words of 4.5 average phonemes, takes approximately 120 ms to complete.

Van Turennout and colleagues (1998) found a similar pattern in LRP response when replacing the semantic task with a syntactic task. In this study the focus was on the time course from syntactic processing (grammatical gender decision: common vs. neuter gender of Dutch nouns) to phonological processing (initial /b/ vs. /s/; initial /k/ vs. /v/). In the first version of this task, syntax determined hand-choice and phonology determined the Go/Nogo decision. Results demonstrated that Go and Nogo waves were significantly different from baseline at 390 ms and 370 ms, respectively. The development of the Nogo wave reflects when participants began processing syntax information. However, the two waves diverged at approximately 410 ms, reflecting when initial phonological information was retrieved, such that Nogo waves fell back to baseline and Go waves continued to develop, reaching maximum amplitude of 760 ms. In version #2, task instructions were switched so as to rule out task set-up effects. Results revealed no significant development of syntactic Nogo waves, yet syntactic Go waves started to develop and were significantly different from baseline at 380 ms.

These findings revealed that processing syntactic information (which started at 370 ms) preceded initial phonological processing (which started at 410 ms) by 40 ms. Thus, after lemma selection, it takes approximately 40 ms to begin construction of the initial word form in an implicit naming task.

Another group of researchers (Schmitt, Munte, & Kutas, 2000) replicated the findings of van Turennout et al. (1997) by using the N200 ERP component, in addition to the previously used LRP, to investigate the time course of semantic processing (object vs. animal) and phonological processing (initial phoneme: vowel vs. consonant). Results for both the N200 and LRP corroborated findings from van Turennout et al.'s (1997) study demonstrating that both components suggest that semantic precedes phonological information. Specifically, the N200 effect, as measured by the mean peak latency, occurred at 380 ms for the semantic=Go/Nogo version and at 470 ms for the phonological=Go/Nogo version, demonstrating that semantic preceded phonological information by approximately 90 ms.

Schmitt, Schiltz, & Zaake (2001) further used both N200 and LRP to investigate the time course of conceptual (heavier vs. lighter than 500 g) and syntactic (female vs. male gender in German) encoding in an implicit picture-naming task. Conceptual focusing preceded gender access by approximately 80 ms, thus lending further support for a serial time course for concept-to-syntax processing. The time course from semantic to syntactic processing was found to take approximately 80 ms. (Schmitt, Rodriguez-Fornells, Kutas, Munte, 2001).

Overall, these time course studies of conceptual, semantic, syntactic and phonological processing have given support to Levelt et al.'s serial model of speech production in the process of lemma to lexeme retrieval. However, recent research by Rahman, van Turennout, and Levelt (2003) has suggested that this serial process can be modulated when semantic retrieval is made more difficult. For instance, in a Go/Nogo task using animal pictures, participants made a decision about a semantic feature (easy decision: size; hard decision:

type of diet) and about the initial segment of (phonology: initial vowel vs. consonant) of the picture name. Results revealed that the onset of phonological processing was not necessarily contingent upon semantic retrieval, as phonological processing began even prior to retrieval of the semantic feature in the hard semantic condition (Rahman, van Turennout, and Levelt, 2003).

In sum, the time course of various stages in lexical access was distinctly detected by mapping a cognitive task onto a motor response, e.g. LRP and/or N200. Findings revealed that processing from the lemma to lexeme stage occurs generally in serial fashion, although not necessarily in a strict serial fashion. These ERP components provide a foundation for a promising future in using ERP methods to analyze other substages of processing required for speech production and to study word retrieval processes in different populations.

1.5. Electrophysiological Evidence of Substages of Phonological Encoding

Studies thus far have focused on the details of time course and the order of conceptual, semantic, syntactic and phonological processing stages. However, there is little research concerning processing within the substages of the general phonological encoding stage. According to Levelt et al.'s model, phonological encoding can be further divided into several substages. This precise detailing of phonological processing is a valuable model for researchers interested in further testing predictions of speech production models. Although we know generally that the second stage of word-form encoding takes place between 275 to 450 ms post picture onset (Indefrey and Levelt, 2004; Levelt, 1989, 2001) more research is needed to obtain a clearer picture of the time course of each phonological substage.

One study explored such aspects of phonological encoding, specifically the time course of ‘metrical spellout’ (retrieval of stress information and syllabification) (Schiller, Bles, and Jansma, 2003). In this experiment an implicit one-decision Go/Nogo naming task was used. The ERP component of interest was the N200. Although the reasoning behind using a one-decision task, rather than the previously used two-decision task in LRP studies is not explained by the researchers, the two-choice task is necessary for eliciting the LRP because it reflects motor preparation, such that the waveform begins once a person is anticipating a response for a task. The anticipation of making a response will initiate an LRP even prior to picture presentation and prior to the recording of the ERP, as a participant might be prepared to perform the task (Go/Nogo), and it will be impossible to identify the actual onset of the signal. Therefore a two-choice task, which is more complex, was created to make the possibility of response preparation prior to picture onset less likely since responding will be contingent on making both a hand-choice and Go/Nogo decision.

The N200, however, reflects response inhibition characterized by a large negativity on Nogo trials relative to Go trials. There is no concern of having a premature onset of the signal due to anticipation, because this deflection is easily detected only at the moment when a response is inhibited, not when it is prepared. For this reason, a two-choice task is unnecessary.

In Schiller et al. (2003), two separate one-decision tasks were used. The decision regarding place of word stress required participants to choose whether the picture name had initial or final stress. The syllabification decision, reflecting the process of placing phonological segments into their correct syllabic frames, required participants to judge whether the first consonant after the vowel was part of the first syllable (e.g. puLpit) or second syllable (e.g. caNoe).

Two early N200 effects reflected speech production components at 250-350 ms and 300-350 ms time intervals, and one late effect was claimed to reflect internal self-monitoring at 400-800 ms. The first early effect for the metric task revealed an unexpected ‘reverse N200’ such that the Nogo wave was more positive than the Go wave. The syllable task revealed a ‘classic N200’ with the Nogo wave more negative than the Go wave. The second early effect showed the opposite pattern, namely the metric task demonstrated the ‘classic N200’ and the syllable task the ‘reverse N200’. The authors speculated that the positive N200 might be related to an overlap with the P300 which reflects task difficulty. However this explanation of the polarity switch and particularly of the positive N200 needs clearer support.

The peak latencies for the metrical and syllable tasks for the first early effect were 255 ms and 269 ms (classical N200), respectively. The second early effect had peak latencies of 335 ms (classical N200) and 329 ms, for the metric and syllable tasks respectively. Thus overall both metric and syllable tasks showed N200 effects during the time window of 250-350 ms, especially at frontal sites. As the time window for these phonological effects occur within the time frame for phonological encoding as reported by Indefrey and Levelt (2000), namely between 275-400 ms, these early effects support the conclusion that they reflect phonological encoding processes for speech production.

The late effect, however, occurred at a much later time (between 400-800 ms) than that reported by Indefrey and Levelt (2004) and thus cannot be explained as reflecting phonological production processing. Thus, the authors suggest that this late ERP component reflects internal self monitoring that occurs before a response is made. This is based on a proposal by Wheeldon and Levelt (1995) that phonological information is available to the speaker only after the full phonological word, placed in an articulatory buffer, is monitored for stress and syllable information. This monitoring process is what Schiller et al. (2003) proposes is reflected in the identified late effect.

Overall, findings from Schiller et al. revealed that there was little difference in peak latency, i.e. information availability, of metrical and syllabic information, thus supporting the theory of parallel processing of encoding for these phonological substages. Additionally, the finding of a positive N200 effect and a late effect suggests that processing beyond retrieval of the component information itself is occurring and might be related to task performance and/or self-monitoring.

In another study, Schiller (2006) investigated the time course of lexical stress encoding in picture naming. Go/Nogo decisions were made regarding position of stress in bi-syllabic words. Results revealed faster RT and N200 latency to initial vs. final stress decisions. These findings support the view that metrical retrieval occurs in an incremental fashion.

Thus overall, research has demonstrated that the N200 can detect the time course for processing of specific phonological encoding substages. Results indicate that metrical encoding of stress and syllabification occurs in parallel fashion and incrementally.

1. 6. Electrophysiological Research and Aging

Much research has been done investigating cognitive processing in the elderly population (Friedman, 2003). For example, investigations into various types of memory, (e.g. episodic memory, working memory), have demonstrated greater variability among older individuals than younger adults. Some studies reveal that older individuals are able to compensate for the aging effects, thereby showing no age-related decline (Craik & McDowd, 1987) while others demonstrate that older individuals are inefficient (Spencer & Raz, 1995; Jonides, Marshuetz, and Smith, 2000). Furthermore, age-related decline in frontal lobe processing is suggested to account for the age-related changes in cognition (Fabiani and Friedman, 1995; Friedman, Cycowicz & Gaeta, 2001; West, 2000).

Additionally, ERP studies have looked at how aging affects processing at specific sublevels (e.g. sensory, lexical, higher-order level thinking) involved within a single complex cognitive task (e.g. lexical and/or sentence processing). Findings have demonstrated age-related ERP changes at particular sublevels and not a general slowing effect that carries over to all sublevels. For example, on an auditory lexical and sentence processing task, the early sensory and attentional components N1 and P2 occurred later (by approximately 25 ms), and they were reduced in amplitude and distributed differently (more frontal) in the older than the younger group, while the later component of semantic processing (N400) was comparable in both age groups.

However, age effects of delays of about 200 ms (a significantly greater delay which cannot be accounted for by the earlier 25 ms sensory delay), were found in the older, as compared to the younger, group on the same task when looking at the N400 as a reflection of understanding message-level context (Federmeier, Van Petten, Schwartz, and Kutas, 2003). Interestingly, these findings demonstrate that although early sensory delays were observed, they did not necessarily carry over to the later cognitive component reflected in the N400. And, when N400 delays were seen as a reflection of processing changes with age on higher-level language processing, these delays were significantly longer than those observed in early sensory processing. This suggests that general slowing with aging does not necessarily translate to neural processing delays across all processing stages.

Modality of testing also plays a role in performance in the aged population. For instance, although auditory tasks demonstrated delayed N1 and P2s, there were no N1 but only P2 delays in visual tasks (Gunter et al., 1992, 1998, as reported in Federmeier et al., 2003). Additionally, ERP components for Go/Nogo visual tasks, as opposed to auditory ones, showed an N200 (reflecting inhibition) and a P300 (reflecting cognitive effort) of greater amplitudes and later peak latencies in older adults (mean age: 58.3 years), as compared to a younger group (Falkenstein et al., 2002).

Fallgatter, Mueller, and Strik (1999) investigated the effects of age on the topography, latency and amplitude of the P300. They noted an anteriorized topographic shift, particularly for the Nogo-P300, yet no latency or amplitude correlation with age. In contrast, Falkenstein et al. (2002) did not find that the topography of P300 and N200 was influenced by age, suggesting that the location of the neural generators is not affected by age. Furthermore, P300 latency, not amplitude, however, was delayed with age in both auditory and visual modalities.

In sum, studies in aging reveal ERP processing delays in older, as compared to younger, adults on various tasks. These latency and amplitude differences reflect age-related changes in early sensory and higher order related language processes, but the higher-order delays cannot be accounted for by the earlier ones.

1.7. The ERP Components: N200, P300, and VEPs

As the above studies have indicated, ERP methodology, recognized for its high temporal resolution (in milliseconds), is capable of indexing the relative timing of substages within phonological encoding. In the present study, the N00, P300 and VEP components will be used to assess timing differences both within and between groups on two Go/Nogo classification tasks.

The N200 is related to response inhibition. When a participant is asked to respond, via a button-press, on Go trials and withhold a response on Nogo trials, the N200 is larger between 100-300 ms over frontocentral sites for the Nogo trials. Thus, increase of the N200 amplitude indicates that analysis of the information to determine whether or not to give a response must have already occurred. It reflects an approximation of the upper limit of when the particular information must have been encoded (not the exact timing since the N200 reveals an endpoint in time when certain information is available for making a metalinguistic decision), making it a useful measure to study language processing. In this experiment the N200 effect will be called the N2d, characterized by Nogo trials that are more negative relative to Go trials (Nogo minus Go waves; see Figure 2).

The P300 is a frontal positivity which is considered a complex component as it indexes more than one function (Johnson, 1988). For instance, in a novelty oddball paradigm, a large amplitude positivity is called a P3a and often follows the Mismatch

Negativity (MMN). This P3a is claimed to reflect involuntary attention to an unexpected novel stimulus (Friedman, Cycowicz, and Gaeta, 2001). However, in an inhibition Go/Nogo paradigm, the P3d follows the N2d and is generally accepted to reflect inhibition (e.g. De Jong et al., 1990; Dimoska, Johnstone, and Barry, 2006; Karlin, Martz, and Mordkoff, 1970; Roberts, Rau, Lutzenberger, and Birbaumer, 1994; Schupp, Lutzenberger, Rau, and Birbaumer, 1994). Schupp et al. demonstrated that the P300 reflects general inhibition that occurs later in processing, and is thus different than the modality-specific N200 inhibition that occurs earlier in time. In this experiment, the P300 effect will be called the P3d, characterized by greater positive amplitude on the Nogo than Go trials. This difference wave is assumed to reflect task difficulty and is referred to in the literature as the P3d (Falkenstein et al., 2002); the greater the task difficulty, the larger the P3d amplitude, and thus the more positive the entire signal.

Lastly, visual evoked potentials (VEPs) are a standard set of early sensory/attentional components elicited to visual information. They are largest at occipital sites, displaying positivity at 150 ms that inverts over the frontocentral sites, and negativity at 200 ms, inverting over the frontal pole (Federmeier et al., 2003; Gokcay, Celebısoy, Gokcay, Ekmekcı, Ulku, 2003; Herbert, Kissler, Junghöfer, Peyk, and Rockstroh, 2006; Odom et al., 2004; Sobótka, Pizlo, and Budohoska, 1984).

These three components, N2d, P3d and VEPs, will be the focus in the present study.

1.8 The Present Study: Research Questions

In summary, previous research on speech production has focused solely on the younger adult, not the older adult, population, yet lexical retrieval has been implicated in aging. The present study, thus, investigated how aging impacts phonological substages in the word-retrieval process. Hence, the first question addressed is: **How do younger vs. older individuals compare in retrieval of phonological information, namely, segmental and syllabic information?**

Moreover, a sub-question related to the first question is how age affects both early vs. late processing stages, in general, during word-retrieval. Are changes in brain processing due to aging manifest at both early and late processing stages or are these stages differentially affected?

Additionally, the time course of conceptual-semantic, syntactic and phonological processes has been studied in the ERP literature and has largely supported the Levelt et al. (1999) serial model in the process of lemma to lexeme retrieval. However, the phonological encoding stage, which includes various substages, has been looked at only generally in the ERP literature. One exception is a study investigating the processing of ‘metrical spellout’ (Schiller et al., 2003), and one investigating lexical stress encoding (Schiller, 2006). These studies have supported the finding of parallel processing for metrical encoding that occurs in an incremental fashion.

The present study was designed to further detail the time course of other substages within phonological encoding, since this overall stage is the one purported to be most responsible for word retrieval problems with aging, as predicted by the TDH. This study aimed at providing refined temporal information regarding the first two phonological substages, segment and syllable retrieval, which are most implicated in lexical access problems. Thus, the second question addressed is: **What is the time course for processing of segmental versus syllabic information? Do these substages proceed in parallel or serial fashion?**

This study used event-related potentials (ERPs), specifically, N200, in an implicit naming Go/Nogo paradigm to investigate the timing of substage phonological information. Differences in processing of these particular phonological substages were investigated as a function of age, as TOT research in the older population invariably pointed to a breakdown at this processing level.

The motivation for this study arose from research investigating TOT states in the non-clinical population (Burke et al., 1991) and from the aphasia literature exploring lexical access problems in the clinical post-stroke population (Dell, Schwartz and Martin, 1997; Wambaugh, Linebaugh, and Doyle, 2001). Results from the typical healthy younger and older adult population established baseline norms of phonological processing for word-retrieval, and also allowed for testing of Levelt et al.'s model of phonological substages in naming. Furthermore, findings from the healthy older population provided a basis of comparison to age-matched patients with aphasia for future ERP studies.

Taken together, the significance of these findings is that our research provides direction to the psychological/cognitive research aimed at improving quality of life with age. Findings from our study presented evidence for particular sublevels of difficulty to be targeted in working towards enhancement of word retrieval in healthy aging. Additionally, findings serve as a compass for future investigations of word retrieval problems in clinical populations. The implications therefore indirectly relates here to aphasia research of assessment and rehabilitation for word-finding difficulties.

1.9 Hypotheses

The TDH proposes that older people are more prone to problems at the phonological level due to weakened connections in memory with age. Additionally, cognitive aging theories (Klatzky, 1988; Salthouse, 1988) suggest that there is cognitive slowing with age. Thus, the following are the findings we anticipated. It was expected that:

1) Reaction-times (RT) would be longer for older, as compared to the younger, adult group on both phonological tasks, as per the TDH.
2) Both participant groups would demonstrate the expected N2d (greater negative amplitude on Nogo than Go trials) and P3d (greater positive amplitude on Nogo than Go trials) effects on the phonological tasks.
3) Older, as compared to younger, adults would demonstrate an N2d and P3d with later peak latency, as per Falkenstein et al.'s (2002) findings regarding visual Go/Nogo tasks, and greater positive amplitude shift, reflecting greater task demand, on both phonological tasks,
4) It was unknown whether older adults, as compared to younger adults, would have greater difficulty in accessing segmental versus syllabic information. The results of this study provide this information. However, given the fact that during a TOT event syllable information is often most likely to be spontaneously available (A.S. Brown, 1991), it was predicted that for the typical aging process, the segment task would be more affected than the

syllable task. This would be demonstrated by later peak latencies on the N2d and P3d and greater positive amplitude shift.

5) The early VEPs will show no significant latency difference between groups, although there will be significant latency differences between groups in both the N2d and P3d components for the later phonological processing. This would indicate that age-effects are not due to generalized cognitive slowing but rather to specific slowing at the later phonological processing stages.

6) The time course for phonological processing of segment and syllable retrieval in younger adults would occur in a parallel fashion, as per Levelt et al. (1991) and similar to findings of Schiller et al. (2003) on metrical stress vs. syllable information in younger adults. This would be demonstrated by comparable N2d latencies on both tasks.

Chapter 2: Method

2.1 Participants

Sixteen healthy younger adults (*M* = 28.3 years, range 23-40, 7 males, 9 females) and 16 healthy older adults (*M* = 73.3 years, range 68-80, 5 males, 11 females) were included in the study (see Table 1) and were reimbursed $10 per hour for participation. Participants were screened over the phone using a background questionnaire (see Appendix A) in order to ensure that they fit the following inclusion criteria: 1) having no previous neurological or psychiatric history, 2) scoring at least 20 or more points on the Mini-Mental State Exam (MMSE; Folstein, Folstein and McHugh, 1975), 3) having adequate hearing and normal or corrected-to-normal vision based on self-report, 4) having a high school (or higher) level of education, and 5) being native speakers of American-English. If potential participants had studied a second language post-puberty, a rating scale was provided in order to ensure that they were highly dominant American-English speakers; a rating of only "poorly" to "somewhat", the lower end of a 4-point scale (1=poorly, 2=somewhat, 3=good, 4=excellent/native-like) regarding proficiency of the second language, was accepted. Younger and older adult participants were matched on these measures. Additionally, self-report of handedness and frequency of word-retrieval problems was obtained (see Table 1).

Exclusion from the study was based on having a history of neurological or psychiatric illness, history of speech-language or learning deficits, less than high-school level of education and knowledge of a second language prior to puberty. A comprehensive examination of auditory skills was not conducted for this experiment as this was a visual study and task-related oral instructions were supplemented with written directions and practice trials. Self-report of auditory and visual skills was supplemented with informal observation of performance on pre-test and practice trials. Accommodations and modifications (speaking loudly in giving oral directions, placement of the monitor at a good visual distance, etc.), were made as necessary to ensure adequate sensory processing for participation of the task at hand. Participants would have been excluded if, given these accommodations, performance on the pre-testing and practice stimuli was compromised, but this was not necessary for the participants tested in this study.

Recruitment was accomplished by distributing posters and fliers on college campuses and senior citizen centers, and via personal referral. IRB approval (#05-02-0709) was granted by the Graduate Center, City University of New York on 3/14/05 and all participants signed an informed consent form (see Appendix B).

2.2. Stimuli

Picture stimuli (digitized bitmap files) were compiled from the colored version of standardized pictures from Snodgrass and Vanderwart (1980). A set of 12 pictures was used for the practice testing performed before each phonological task (10 practice items/task) (see Appendix C). Experimental stimuli consisted of a different set of 28 pictures (see Appendix D). Picture names were classified as follows: seven final /n/ 1-syllable words, seven final /n/ 2-syllable words, seven final /r/ 1-syllable words, and seven final /r/ 2-syllable words. Each picture was repeated ten times (once per block) within a given task (segment and syllable) yielding a total of 280 trials per task (140 Go and 140 nogo responses).

This set-up, of using a small group of pictures that are repeated multiple times, is commonly used in the ERP and speech production literature (e.g. van Turennout et al., 1997, 1998; Schmitt et al., 2000, 2001). Repetition of the pictures ensures the reduction of errors in task performance, thus allowing for investigation into the normal process of successful lexical access. Furthermore, minimizing error opportunities decreases the occurrence of error-related ERP negativities. These error-related negativities occur shortly after errors, particularly after commission errors (Falkenstein, Koshlykova, Kiroj, Hoormann, and Hohnsbein, 1995). The use of a more challenging paradigm would require excluding error trials and those following error trials, and thus reduce the signal/noise ratio. Based on pilot testing, it was determined that a reliable N2d could be obtained with a minimum of 70-100 trials. We included 280 trials per task, many more trials beyond 70-100, as errors and motor artifacts were expected.

Each of the ten blocks of 28 items was pseudo-randomized such that no more than three Go or three Nogo responses occurred consecutively. As well, pictures from the same semantic group (e.g. foods, body parts, animals) were separated by at least two non-semantically related items in order to minimize any semantic priming advantage in retrieval of picture names within the same category.

The 28 picture names were of moderate frequency with an average word frequency of 37 per million (range: 6 to 148 per million, SD=33) (Francis and Kucera, 1982) and mean number of phonemes of 3.6 (range: 1 to 6 phonemes, SD=1.2). For the segment task, the pictures were divided into Go vs. Nogo categories based on final phoneme (/n/ vs. /r/). The mean frequency and number of phonemes of final-/n/ vs. final-/r/ picture names were comparable at 39 (SD=30) and 35 (SD=37) per million (t(25)=2.0595, p=0.7639), and 4 (SD=1.0) and 3.2 (SD=1.3) phonemes (t (24)=2.0639, p=.0747), respectively.

For the syllable task, the picture names were divided into Go vs. Nogo categories based on number of syllables (one vs. two). The mean frequency (with standard deviation and median frequency values), and number of phonemes of 1-syllable vs. 2-syllable picture names were significantly different at 50 (SD=52; median=31.5) and 24 (SD=14; median=19) per million (t (16)=2.1199, p=.0478), and 2.8 (SD=.89; median=3) and 4.4 (SD=.76; median=4) phonemes (t (25)=2.0595, p=.0000), respectively (see Appendix E). This word-frequency difference was expected given that one-syllable words are often more frequent than two-syllable words. Pictures were input into an E-prime program for output onto a computer screen.

2.3. Design

Each participant performed two phonological tasks. In task #1, participants were instructed to make a segment decision (final /n/ vs. /r/) about the picture name, which was the same type of choice used in the van Turennout et al. (1997) study. Two instruction sets were created and participants were randomly assigned to receive either one of these instructions. Namely, half of the participants were asked to “Go” (i.e. press the button) if the name ended with a /n/ sound and “Nogo” (i.e. don’t press the button) if the name ended with a /r/ sound, while the other half of the participants were asked to “Go” if the name ended with a /r/ sound and “Nogo” if it ended with a /n/ sound.

In task #2, participants were instructed to make a syllable judgment. Again two instruction sets were created and participants within each age groups were randomly assigned to receive either one of these instructions. Half of the participants were asked to “Go” if the name had one-syllable and “Nogo” if the name had two-syllables, while the other half of the participants were asked to “Go” if the name had two-syllables and “Nogo” if it had one-syllable.

Participants in each age group were randomly assigned to one of the eight possible task arrangements (there were two participants per task order), in order to control for order effects: 1) task 1: Go=n, task 2: Go=1-syllable, 2) task 1: Go=n, task 2: Go=2-syllable, 3) task 1: Go=r, task 2: Go=1-syllable, 4) task 1: Go=r, task 2: Go=2-syllable, 5) task 1: Go=1-syllable, task 2: Go=n, 6) task 1: Go=1-syllable, task 2: Go=r, 7) task 1: Go=2-syllable, task 2: Go=n, 8) task 1: Go=2-syllable, task 2: Go=r. A block design was used in order to reduce the possibility of confusion in performing the task, as the same pictures were used for each condition.

2.4. Procedures

Prior to inclusion in the study, potential participants were screened over the telephone, using the background questionnaire to ensure appropriateness for this study. The study was explained to the participants on the day of testing and they signed an approved IRB informed consent form. They were then pre-familiarized with the experimental and practice picture names to be used in the experiment.

Pictures were presented on a computer screen with their given label. Then a practice block of pictures without their written labels was shown. Each picture was preceded by a fixation point in order to acquaint participants with the timing per trial for testing procedures. Participants were instructed to name the picture aloud as quickly and accurately as they could. This pre-familiarization testing guaranteed that participants knew the correct label to use in the experiment. It also ensured that participants would not experience a TOT state. This was important, as the purpose of this study was to evaluate the process of normal, not disordered, lexical access in both healthy younger and older adults. Furthermore, by reducing the possibility of a high error rate, we reduced the possibility of the error negativity and increased the likelihood of obtaining a large N2d effect (Falkenstein et al., 1999).

Participants were then fitted with a 65 channel Geodesic Sensor net and then seated in a comfortable chair in a 9'x10' ft electrically shielded booth in front of a computer screen. Test stimuli were presented on the screen and behavioral responses were collected using E-prime software and a Serial Response Box.

Ten practice trials (five Go and five Nogo conditions) were given before each task (segment and syllable) to ensure participants understood the directions. In order to minimize motor artifacts, participants were told to only implicitly name the picture and to control eye blinks and other movements until after the picture was removed from the screen. Each task was divided into 10 blocks of 28 pictures (each block took approximately 1½ minutes) with the opportunity for breaks in between blocks.

A trial began with a fixation point (+) in the middle of the computer screen for .75 seconds, followed after an additional .75 seconds by a picture. The picture was displayed for 1.5 seconds. The inter-trial interval (ITI) was .75 seconds, followed by the fixation point again to indicate an upcoming new trial (see Appendix F). Each task of ten blocks took approximately 15 minutes. After the first task, ERP equipment was re-calibrated and impedances were re-measured (below 40 kΩ) prior to administration of the next task.

Again, practice items preceded administration of the experimental blocks. The entire experiment took approximately 1 ½ hours. For a summary of the experimental timeline see Appendix G.

2.5. Apparatus and Recordings

Electroencephalogram (EEG) data was collected via an Electrical Geodesics 200 system using a Geodesic Sensor net, an arrangement of 65 silver/silver-chloride (Ag/AgCL) plated electrodes in sponges which was soaked in a mild saline solution for approximately five minutes prior to placement on the scalp (see Figure 5 for electrode locations). The vertex served as the reference during data collection. Vertical and horizontal eye movements and eye blinks were monitored on the EEG Dense Waveform Display at the following electrodes: vertical—via one electrode placed one cm below each eye and frontal electrodes Fp1 (left) and Fp2 (right); horizontal—via electrodes 64 (left) and 63 (right) on each side of the eye. Electrode impedances were kept under 40 kΩ, which is acceptable for the Geodesic amplifier input impedance of 200 MΩ (Ferre, Luu, Russell, & Tucker, 2001).

The EEG was amplified with a hardware filter bandwidth (0.1-41.3 Hz) using Geodesic Amplifiers. A Geodesic software system (*Netstation 4.0*) in continuous mode was used to acquire data at a sampling rate of 250Hz per channel for later off-line processing. During data acquisition, all channels were observed by the experimenter to monitor the participant’s state, artifact due to electrical interference, defective electrode contact or excessive muscle movement.

2.6. Data Analysis

2.6.1. Behavioral Analysis

Behavioral response data were examined for errors. A trial was marked erroneous and eliminated from the data set ERP if the following occurred: 1) a button-press response was not detected within the time-frame from picture onset until 2.25 seconds after picture presentation and/or 2) an error response was given, i.e. not responding on Go trials (omission errors) or responding on Nogo trials (commission errors) responses. Group reaction times (RTs) were compared for variance, as it was assumed that older adults may show greater variability related to word retrieval. However, there were no outliers greater than three standard deviations (SD) and thus no participant's data points were removed from the overall mean RT data. T-tests were performed to examine group differences for RT. Additionally, due to the high performance (near ceiling) in both groups, a median test and Chi-Square test was performed to compare error responses between groups.

2.6.2. Electrophysiological Analysis

After recording, the continuous EEG was processed off-line and segmented into epochs with an analysis time of 1500 ms post-stimulus and 100 ms pre-stimulus baseline. ERPs were time-locked to the appearance of the picture. The 100 ms pre-stimulus period included the end of the appearance of the fixation point and the blank screen.

Epochs were baseline corrected and then artifact decontamination procedures were employed. Using *Netstation 4.0* software, channels in a single epoch with either fast average amplitude exceeding 200 µV, with differential amplitudes exceeding 100 µV, or with zero variance, were marked as bad channels. A channel that was a bad channel in 20% of trials was considered a bad channel in all trials. A trial was rejected if it contained more than 10 bad channels or if electrophysiological activity exceeded +/- 75 µV due to lateral eye movements. Channels with high artifact were replaced by interpolation using adjacent sites. ERP averages were calculated for both tasks and referenced to the average-reference. The averaged response to the Go stimuli was then subtracted from that of the Nogo stimuli to derive difference waveforms.

2.6.2.1. N2d Analysis

The first negative peak between 251-600 ms was called the N2d (Nogo minus Go waves) (see Figure 2). This time range was determined using Global Field Power (GFP) analysis (Lehmann and Skrandies, 1980), a method that allows one to determine the point where the greatest variance occurs across all electrode sites. To obtain GFP, the standard deviation of the absolute voltage deviations of the 63 scalp sites from the average was calculated for each participant. The analysis was done on the grand average (GAV) difference wave data for the younger and older participants in each condition (segment, syllable), separately. First, the latency of the greatest standard deviation peak was identified. Then, the earliest and latest time points (trough to trough) around the peak were set as the start and end points of the N2d. In Figures 3 and 4 the N2d is seen as a very steeply sloping region of the GFP plot. Observation of the raw data corroborated the selection of 251-600 ms as the N2d time range chosen for further statistical analysis. The following peak was P3d.

Frontal electrode sites Fz7 (closest to Afz, Geodesic site 7) and Fz (Geodesic site 4), and central electrode site Cz (vertex, Geodesic site 65), where N2d is expected to be largest (see Figure 5), at time intervals 251 and 600 ms, were selected for analysis. The mean amplitude for seven 50-ms intervals (251-300 ms, 301-350 ms, 351-400 ms, 401-450 ms, 451-500 ms, 501-550 ms, and 551-600 ms) was calculated. These finer-grained intervals allowed for the determination of when the difference between conditions (N2d) begins, in a more objective manner than visual inspection. Repeated measures three-way ANOVAs were performed in a Response (Go, Nogo) by Site (Fz7, Fz, Cz) by Time (7 intervals) model to verify the presence of N2d for each Stimulus (segment and syllable) and Group. Then, a repeated measures two-way Response x Site ANOVA for each time interval was performed as a follow-up to the significant three-way interaction, in order to objectively specify which sites showed significant differences in the N2d. All two-way interactions including Response were followed up with Post-hoc Tukey's Honestly Significantly Different (HSD) analysis.

To examine whether the incidence of N2ds differed for each group and for each stimulus, analyses using the subtraction waveforms were carried out only at site Fz7 and at narrowed time intervals, where the greatest response was found. Repeated measures ANOVAs were performed in a Group (younger, older) by Stimulus (segment, syllable) by Time (five 50-ms intervals: 301-350 ms, 351-400 ms, 401-450 ms, 451-500 ms) analysis. All significant three-way interactions were followed up with two-way ANOVAs and significant two-way interactions including Group and /or Stimulus were followed up with Post-hoc Tukey's HSD analysis.

2.6.2.2. P3d Analysis

Following the negative N2d peak, a late positivity between 601-1100 ms was observed, which is consistent with the P3d (Nogo minus Go) reported in Falkenstein et al. (2002). This time range was determined using GFP analysis of the difference wave data for the younger and older participants in each condition (segment, syllable), separately. Frontal and central sites (Fz7, Fz, Cz) (see Figure 5), where P3d is expected to be largest, at time intervals 601-1100 ms, were selected for analysis. The mean amplitude for ten 50-ms intervals (601-650, 651-700 ms, 701-750 ms, 751-800 ms, 801-850 ms, 851-900 ms, 901-950 ms, 951-1000 ms, 1001-1050 ms, and 1051-1100 ms) was calculated.

Similar to N2d analyses, a three-way ANOVA [Response (Go, Nogo) X Site (Fz7, Fz, Cz) X Time (ten intervals)] was conducted. This was followed up by two-way Response x Site ANOVAs for each Group and Stimulus separately. All two-way interactions including Response were followed up with Post-hoc Tukey's HSD analysis.

Additionally, a three-way ANOVA using difference waveforms (Go minus Nogo) at site Fz7 was conducted with Group, Stimulus, and Time as factors. All three-way interactions were followed up by two-way ANOVAs, and significant two-way interactions, including Group and /or Stimulus, were followed up with Post-hoc Tukey's HSD analysis. A t-test contrast analysis was performed in instances where post-hoc Tukey testing was not sensitive enough to reveal a particular time interval where the P3d was significant.

2.6.2.3. VEP Analysis

The early sensory visual evoked potentials (VEPs) are largest at occipital sites, displaying positivity at 150 ms that inverts over the frontocentral sites, and negativity at 200 ms, inverting over the frontal pole (Federmeier et al., 2003; Gokcay, Celebısoy, Gokcay, Ekmekcı, Ulku, 2003; Herbert, Kissler, Junghöfer, Peyk, and Rockstroh, 2006; Odom et al., 2004; Sobotka, Pizlo, and Budohoska, 1984). To compare latency of VEPs between groups a three-way ANOVA of Stimulus (Segment, Syllable) X Time (three 50-ms time intervals between 100 to 250 ms: 100-150 ms, 151-200 ms, 201-250 ms) X Group (Younger, Older), was conducted for Go and Nogo responses separately, at central occipital site Oz. Two-way interactions were followed up with Tukey post-hoc testing.

For all component analyses, the statistically significant findings are reported with their effect sizes. Statistical analysis was performed using Statistica 7.1. All *p* values reported for significant interactions involving factors with more than two levels (except time) have been corrected for sphericity using Greenhouse Geisser. Effect sizes reported as η^2 can be interpreted as large (.25), medium (.09) and small (.01) (Jia, Kohnert, Collado & Aquino-Garcia, 2006). Topography of the voltage responses was computed using BESA 5.3.9 to help determine which electrodes should be used for analysis of N2d, P3d, and VEP components.

3. Results

This section reviews first behavioral findings followed by electrophysiological findings. Furthermore, results are linked directly to hypotheses proposed at the end of Chapter 1, although they are not addressed, in this section, in numerical order.

3.1. Behavioral Data: Button-press Reaction Times

Results of RT data revealed that the older group demonstrated longer RT as compared to the younger group on both phonological tasks as predicted by the TDH (hypothesis #1). In a two (Group) x two (Stimulus) ANOVA, there was a significant main effect for Group (F (1, 60) =18.718, p=0.000) such that the older participants were slower than the younger participants by 96 ms on the segment task and 106 ms on the syllable task, as shown in Table 2. However, there were no main effects for Stimulus (F (1, 60) =0.090, p=0.766), nor a Group x Stimulus interaction (F (1, 60) =0.053, p=0.819).

In terms of omission errors (i.e. false negative responses--not responding on Go trials), there was a significant main effect of Group (F (1, 60) = 12.182, p=.001), such that overall, on both tasks, the older group had significantly more omission errors (mean=4.9, SD=5.3) as compared to the younger group (mean=1.7, SD=2.2). There was also a significant main effect of Stimulus (F (1, 60) = 8.722, p=.004), such that overall, across both groups, there were significantly more omission errors on the syllable (mean=4.7, SD=5.6) than on the segment task (mean=1.9, SD=1.8) (see Table 3).

Additionally, a Group x Stimulus interaction approached significance (F (1, 60) = 3.789, p=.056), demonstrating that the older group produced more omission errors on the syllable (mean=7.2, SD=6.5) than the segment task (mean=2.6, SD=1.9), while the younger group did not perform significantly differently on the two tasks (mean=1.2, SD=1.3, and mean=2.1, SD=2.8, on the segment and syllable tasks, respectively) (Table 4). Figure 7 shows the distribution of omission errors on the syllable task (range: 1-22 errors). Six out of the 16 older participants produced more than seven errors but only one of 16 younger participants produced over seven errors.

In terms of commission errors (i.e. false positive responses--responding on Nogo trials) there were no significant main effects for Group (F (1, 60) =.817, p=.370) as both groups had comparable mean commission errors overall, and Task (F (1, 60) =.108, p=.744) as there were comparable mean commission errors overall on each task as shown in Table 3. There was also no significant Group x Task interaction (F (1, 60) = .331, p=.567), as both groups had comparable commission errors on each task, as shown in Table 4.

3.2. Electrophysiological Data

3.2.1. Presence of N2d

N2d is expected to be largest at fronto-central sites and invert in polarity (i.e., show positivity) at the mastoids. The topographical maps for the two tasks in Figure 8 a-d illustrate the frontocentral negativity and mastoid positivity in both the younger and older groups. In hypothesis 2, we predicted that both participant groups would demonstrate the expected N2d effect (greater negative amplitude on Nogo than Go trials) on the phonological tasks. To test this hypothesis, a three-way ANOVA of Response (Go, Nogo), Site (Fz7, Fz, Cz), and Time (seven intervals) was conducted on each group and task separately. In the following set of analyses, only main effects or interactions including Response are reported, because only these cases indicate the presence of N2d.

In the younger group, results revealed a significant Response X Time interaction on both tasks [F(6, 90)=8.493, p=0.005, η2= 0.362 on the segment task; F(6, 90)=10.617, p=0.002, η2=0,414 on the syllable task]. Post-hoc testing revealed a significant response at later time intervals, namely, 551-600 ms on the segment task, and 501-600 ms on the syllable task. Observation of the graphs in Figures 9 a and b, however, reveals that this response really reflects the onset of the P300, not the N200, as the Nogo trials had a larger positivity than the Go trials. Additionally, results revealed a significant Response X Site X Time interaction on both tasks [F (12, 180) = 4.900, p = 0.008, η2 =0.246 for the segment task; F (12, 180) = 6.188, p = 0.003, η^2 = 0.292 for the syllable task].

In the older group, results revealed a significant Response X Site interaction on both tasks [F (2, 30) =5.119, p= 0.026, η2 = 0.254] for the segment task; F (2, 30) = 4.384, p= 0.040, η2 = 0.226 for the syllable task]. Post-hoc Tukey testing, however, was not sensitive enough to reveal at what site the N200 was most significant. The following set of analyses will reveal this information. Next, a significant Response X Time interaction was found only for the syllable task [F (6, 90) = 4.587, p= 0.026, η^2 = 0.234]. Post-hoc testing revealed a significant response only at later time intervals 551-600 ms. Observation of the graph in Figure 10 reveals that this response really reflects the onset of the P300, not the N200, as the Nogo trials had a larger positivity than the Go trials.

Lastly, results revealed a significant Response X Site X Time interaction only on the syllable task [F (12, 180) = 7.162, p = 0.008, η2= 0.323].

Two-way ANOVAs of Response (Go, Nogo) x Site (Fz7, Fz, Cz) for each time interval were performed for each group separately to follow-up the significant three-way interaction found in the previous analysis. Results indicated the specific time intervals of the N2d. See Table 5 for summary of statistically significant N2d findings.

Findings revealed a significant main effect of Response in the younger group at times 301-450 ms on the segment task, and Response x Site interactions at times 351-450 ms on the syllable task, as shown in Table 5 (see also Figure 11a for raw waves). Additionally, at time 551-600 ms, a main effect of Response [F (1, 15) = 7.363, p= 0.016, η2= 0.329] and Response X Site interaction [F (2, 30) = 4.676, p= 0.024, η2= 0.238] was found only for the syllable task. However, these findings at this time interval do not reflect the N200. Observation of the graphs in Figure 12 reveal that this later effect really reflects the onset of the P300, as the Nogo trials were more positive than Go trials.

In the older group, a significant Response x Site interaction was found at times 401-500 on the segment task, and at times 451-500 on the syllable task, as shown in Table 5 (see Figure 11b for raw waves). Post-hoc testing, following up the two-way ANOVAs, indicated that the response difference was greatest at site Fz7 in the younger group on the syllable task, and in the older group on both tasks. Additionally, at time 501-550 ms, there was a Response X Site interaction for both the segment [F (2, 30) = 4.290, p= 0.048, η2= .222] and syllable tasks [F (2, 30) = 7.445, p= 0.013, η2=0.332], and at time 551-600 ms a Response X Site interaction [F (2, 30) = 6.472, p= 0.019, η2= 0.301] only for the syllable task. Post-hoc testing, however, did not reveal a particular site where the N200 response was significant. Furthermore, observation of the graphs in Figure 13 a and b reveal that at site Fz and Cz the effects do not reflect an N200 response but rather a P300, as the Nogo trials were more positive than the Go trials.

In summary, both groups showed significant N2ds for both tasks that were generally largest at Fz7, but the N2d appears to begin 100 ms later in the older compared to the younger group as shown in Table 6, Figure 14 (raw waves), and Figure 15 (difference waves). This difference will be tested directly in the next set of analyses.

3.2.2. Comparison of Groups and Tasks using N2d Subtraction Waveforms

In Hypothesis 3, we predicted later N2ds for the older than the younger group, and in Hypothesis 4, we suggested that the difference between groups would be greater for the segment than the syllable task. To test these hypotheses, three-way ANOVAs of Group (younger, older), Stimulus (segment, syllable) and Time (four 50-ms time intervals from 301-500 ms were conducted using subtraction waveforms (Nogo minus Go) at site Fz7 only, where N2d was shown to be generally largest in the previous analysis. Only four time intervals (from 301-500 ms) were used in this analysis because the previous ANOVAs indicated that the N2d occurred in this time-range.

Results revealed a significant Time X Group [F (3, 90) = 6.105, p = 0.005, $\eta 2$ = 0.169] interaction. Examination of Figure 16 shows that the N2d peaks later in the older group (at times 451-500 ms), than in the younger group (at times 400-451 ms) on both phonological tasks, although pair-wise post-hoc testing did not reveal where the significant group difference lie ($p > 0.05$). Additionally, a Stimulus x Time interaction [F (3, 90) = 4.175, p = 0.022, $\eta 2$ = 0.122] was found. Pair-wise post-hoc testing revealed that the segment task had greater N2d amplitude than the syllable task from 301-350 ms, suggesting an earlier onset (below baseline) for the segment task for both groups (Figure 17). This finding does not suggest particularly greater difficulty on the segment compared to the syllable task for the older group, as predicted in Hypothesis 4 (Figure 14).

In Hypothesis 6, we predicted that the younger group should show similar timing of access to segment and syllable information, although the previous analysis suggests some difference. To examine this more closely we also performed two-way ANOVAs with Stimulus (segment vs. syllable tasks) and Time (four 50-ms time intervals from 301-500 ms), for each group separately, at site Fz7. Results revealed no significant task difference in the younger group, despite an apparent 50-ms difference in the previous analyses comparing Nogo and Go responses directly and in the analysis including both groups (see Figure 18a). However, the older group maintained the significant Stimulus by Time interaction [$F(3, 45) = 4.297$, $p = 0.020$, $\eta 2 = 0.223$] seen previously, demonstrating greater N2d amplitude in the 301-350 ms interval on the segment compared to syllable task. This finding indicates earlier onset of access to segment than syllable information for the older participants (see Figure 18b).

In sum, a significant N2d (greater negativity for the Nogo compared to the Go stimulus) was found most prominently generally at fronto-central site Fz7, in both groups and on both tasks. At this site, group differences were noted such that the younger group demonstrated the N2d effect earlier, at times 301-450 ms on the segment task and at times 351-450 ms on the syllable task (although the within-group task difference was not significant); in contrast, the older group demonstrated the N2d effect later, at 351-500 ms on the segment task, and 451-500 ms on the syllable task. Additionally, only the older group demonstrated a significant within-group difference in access of segment vs. syllable information, showing earlier access to segmental information.

3.2.3. Presence of P3d

P3d is expected to be largest at central (Bekker, Kenemans, Hoeksma, Talsma, and Verbaten, 2005) or fronto-central sites (De Jong, Coles, Logan, and Gratton, 1990) and invert in polarity (i.e., show negativity) posteriorly. The topographical maps for the two tasks in Figure 19 a-d illustrate the frontocentral positivity and posterior negativity. In hypothesis 2, we predicted that both participant groups would demonstrate the expected P3d effect (greater positive amplitude for the Nogo compared to the Go trials) on the phonological tasks. To test this hypothesis three-way ANOVAs of Response (Go, Nogo), Site (Fz7, Fz, Cz) and Time (ten intervals, range: 601-1100 ms) was conducted on each group and task separately. In the following set of analyses, only main effects or interactions including Response are reported, because only these cases indicate the presence of P3d.

In the younger group on the segment task, results revealed a significant Response X Time interaction [$F(9, 135) = 10.484$, $p = 0.003$, $\eta 2 = 0.411$]. Post-hoc testing showed that a significant P3d occurred at times 601-750 ms (see Figure 20). For the syllable task, a Response X Site [$F(2, 30) = 4.837$, $p = 0.028$, $\eta 2 = 0.244$] and a Response X Time [$F(9, 135) = 3.243$, $p = 0.042$, $\eta 2 = 0.178$] interaction were found. Post-hoc testing revealed a significant P3d at site Fz7 and at times 601-700 ms (see Figure 21). In the older group, results revealed a main effect of Response on both the segment [$F(1, 14) = 7.563$, $p = 0.016$, $\eta 2 = 0.351$] and syllable [$F(1, 15) = 6.134$, $p = 0.026$, $\eta 2 = 0.290$] tasks.

Two-way ANOVAs of Response (Go, Nogo) x Site (Fz7, Fz, Cz) for each time interval were performed for each group separately to determine which sites showed significant P3ds at which specific time intervals. In the following set of analyses, only main effects or interactions including Response are reported, because only these cases indicate the presence of P3d.

Findings revealed a significant main effect of Response in the younger group at times 601-750 ms on the segment task, and main effects of Response or interactions of Response x Site at times 601-700 ms on the syllable task (see Figure 11a of raw waves and Figure 18a of difference waves). Table 7 displays the significant findings in the younger group. Additionally, a significant Response x Site interaction was found for the syllable task at times 701-750 ms [F (2, 30) = 4.241, p= 0.039, $\eta2$ =0.220], 901-950 ms [F (2, 30) = 3.766, p=0.053, $\eta2$ = 0.201], and 951-1000 ms [F (2, 30) = 4.076, p= 0.054, $\eta2$ = 0.214]. Pair-wise post-hoc tests did not reveal a particular site where the P3d response was significant. However, observation of the graphs in Figure 22 reveals that the P3d effect (Nogo trials more positive than Go trials) was maintained at site Fz7 at all times, and at site Fz at time 701-750 ms.

In the older group, a main effect of Response was found at time intervals between 601-950 ms on the segment task, and a main effect of Response or interaction of Response x Site at time intervals between 601-800 ms on the syllable task (see Figure 11b of raw waves and Figure 18b of difference waves). Table 8 displays the significant findings in the older group. Post-hoc testing indicated that the significant P3d in both groups and on both tasks was greatest at site Fz7 ($p < 0.05$). However, at times 601-650 ms, in the younger group both site Fz7 and Fz was significant and in the older group sites Fz and Cz were significant.

In summary, both groups showed significant P3ds that were generally largest at Fz7, for both tasks. Additionally, the P3d was significant for a longer time (200 ms) in the older, as compared to the younger, group on the segment task. On the syllable task, the younger group had two significant P3d peaks (601-750 and 901-1000 ms) while the older group maintained one P3d peak from 601-800 ms (see Figure 15). Table 9 displays a summary of the P3d latency range for both groups on each task.

3.2.4. Comparison of Groups and Tasks using P3d Subtraction Waveforms

In Hypothesis 3, we predicted greater P3d latency and amplitude in the older than the younger group, and in Hypotheses 4, we suggested that the difference between groups would be greater for the segment than the syllable task. To test these hypotheses, three-way ANOVAs of Group (younger, older), Stimulus (segment, syllable) and Time (seven 50-ms time intervals from 601-950 ms) were conducted using difference waveforms (Nogo minus Go) at site Fz7 only, where was shown to be equally large in the previous analysis. Only seven time intervals (from 601-950 ms) were used in this analysis because the previous ANOVAs indicated that the greatest P3d occurred within this time-range. Results revealed a Time X Group interaction [F (6, 180) = 3.431, p = 0.003, $\eta 2$ =0.103], however, post-hoc testing did not reveal a particular time interval where the P3d was significant for the tasks (see Figure 23a). Thus a two-way Time x Group ANOVA, for each task separately, was conducted to determine the time interval where a P3d was significant for each task. Findings revealed a Time x Group interaction [F (6, 180) =

5.666, p = 0.000, η2 =0.159] on the segment task only (see Figure 23b). However, post-hoc testing again did not indicate a particular time interval where the P3d was significantly different, because of the conservative nature of the test. Thus, a t-test of contrast analysis for particular time intervals 701-950 ms, the intervals with observed group differences on the segment task (see Figure 23b), revealed a significant group difference at times 851-950 ms. This finding suggests particularly greater general cognitive effort in the older, as compared to the younger, group only on the segment task, not on the syllable task. This finding for the segment task was predicted in Hypothesis 3, however, results for the syllable task was not predicted.

Additionally, there were no significant differences between tasks in either group. This finding does not suggest particularly greater cognitive effort on the segment compared to the syllable task for the older group, as predicted in Hypothesis 4. However, Figure 18a of difference waves in the younger group, shows a different P3d morphology on the segment vs. syllable task, namely a two-peaked morphology for the syllable task.

In sum, a significant P3d (greater positive amplitude for the Nogo compared to the Go trials) was equally prominent at frontocentral site Fz7, in both groups and on both tasks during times 651-1000 ms. There was a significant group P3d amplitude difference only on the segment, not the syllable, task at times 851-950. There was no significant task difference in either group.

3.2.5. VEP Analysis

VEPs are expected to be largest at occipital sites, (e.g. Oz, O1, and O2) and to invert in polarity over frontocentral sites. The topographical maps for the two tasks in

Figure 24 illustrate this topography of a posterior positivity at around 150 ms that inverted over the frontocentral sites, and posterior negativity at 200 ms that inverted over the frontal pole.

In Hypothesis 5, we predicted that both participant groups would demonstrate comparable latency for the early VEPs, indicating similar sensory processing with age. To test this hypothesis, a three-way ANOVA in younger vs. older participants (Group), on both the segment and syllable tasks (Stimulus), at each Time (three 50-ms time intervals: 100-150 ms, 151-200 ms, 201-250 ms) for Go and Nogo responses separately, was conducted. Only site Oz was used in this analysis because previous research has indicated that VEPs are largest at this site (Gokcay, Celebısoy, Gokcay, Ekmekcı, Ulku, 2003; Herbert, Kissler, Junghöfer, Peyk, and Rockstroh, 2006; Odom et al., 2004; Sobotka, Pizlo, and Budohoska, 1984).

Findings revealed no group VEP latency differences. This confirms Hypothesis 5 of comparable sensory processing with age. However, a Time x Group interaction for Go and Nogo response trials was found. Figure 25 shows that the older group had greater negative amplitude than the younger group, during time interval 201-250 ms. Post-hoc testing on the Go, not the Nogo trials, substantiated this finding.

In sum, both groups presented with VEPs and there were no group VEP latency differences. This confirms Hypothesis 5 of comparable sensory processing with age. However, greater VEP amplitudes in the older group revealed that greater visual attention is expended, with age, to perform the tasks.

4. Discussion

The literature in aging and naming has indicated that word finding abilities increase in frequency with age (e.g., Albert et al., 1988; Ardila & Rosselli, 1989; Barresi, Nicholas, and Tabor Connor, 2000; Burke et al., 1991; Goulet, Ska, and Kahn, 1994; MacKay, Conner, Albert and Obler, 2002; Ramsay et al., 1999). Previous research has provided data to support the Transmission Deficit Hypothesis (TDH) that the source of this difficulty lies at the phonological encoding level due to reduced transmission of available semantic/syntactic information to the phonological system (Cross and Burke, 2004; Abrams, et al., 2003; White and Abrams, 2002; James and Burke, 2000; Heine, et al. 1999; Rastle and Burke, 1996; Burke, et al., 1991). The current study adds to the body of evidence in support of this hypothesis, as older adults retrieved phonological information at significantly later times as compared to younger adults. In particular, this study focused on two phonological sublevels, namely segmental and syllabic retrieval, which are implicated in aging. These findings will be discussed in greater detail below.

4.1. Behavioral Data

Differences were found both in reaction time (RT) and in the type of errors produced. However, it should be noted that overall, both younger and older groups performed with high accuracy on the segmental and syllabic phonological tasks. This finding of ceiling performance was desired: 1) because our study was interested in the normal process of phonological retrieval *sans* TOTs, and 2) in order to increase the probability of obtaining a large N2d effect by reducing the occurrence of the error negativity, a phenomenon where a negative component occurs shortly after errors and particularly after commission errors (Falkenstein, Koshlykova, Kiroj, Hoormann, and Hohnsbein, 1995). Thus, our design purposely aimed at ensuring high accuracy, e.g. via a pre-familiarization task and using a small set of repeated pictures.

4.1.1. Reaction time

RT data revealed a group difference as the older group demonstrated a longer RT as compared to the younger group on both phonological tasks. This was expected given previous research findings of slowed reaction time with age on naming tasks (Goodglass, Theurkauf, and Wingfield, 1984) and on cognitive tasks generally (Brébion, 2001; Falkenstein, Hoormann, and Hohnsbein, 2002; Falkenstein, Yordanova, and Kolev, 2006; Posner and Rueda, 2002; Salthouse and Berish, 2005). Our findings of a 96 ms and 106 ms delay in the older group, on the segment and syllable tasks, respectively, fell near, albeit on the later end of, the range of delays reported in the literature. The different tasks, experimental conditions, and age range of the older group used in the studies is likely to have contributed to the difference in the amount of delay between this study and previous studies.

First, the extent of RT delays are influenced by task complexity; the simpler the Go/Nogo decision, for example, about letters K and L as in the Falkenstein et al. (2002) study, the less the delay observed. Our task, however, required participants to make a complex phonological decision during implicit picture naming, thus explaining the greater RT delays evidenced. Second, studies that imposed time pressure, e.g. respond within 400 ms as in the Falkenstein et al. (2002) study, evidenced shorter RT delays. Our study, however, did not impose time demands. The maximum time window for a response was 2.25 seconds, although participants were encouraged to respond both quickly but without sacrificing accuracy. Third, studies that allowed for extensive practice of the tasks, such as, full-day training on a separate day as in the Falkenstein et al. (2002) study, evidenced reduced RT delays. Our study only included ten practice trials before each phonological task to acquaint the participants with the testing situation and assure that they could perform it. Lastly, in many studies, the age of participants included in the “older group” was a maximum of 65 years (Falkenstein et al., 2002, 2006), while our study focused on an older population of 65 to 85 years. Further studies will be needed to determine to what extent these various factors contribute to the observed latency delay.

Additionally, RT differences did not reveal within group effects as segmental and syllabic information was retrieved at the same time for the younger and older group, although there was an overall delay in retrieval for the older group. This finding, thus, suggests that the two tasks were equivalent with regards to difficulty.

4.1.2. Mean Errors

The number of commission errors was comparable across groups and tasks. However, with regards to the number of omission errors, there were between group and within group (only for the older group) differences. More specifically, on both phonological tasks, there were more omission errors in the older, as compared to the younger, group. Our finding differs from data reported in Falkenstein et al. (2002) of negligible omission errors (0.2%) among both younger and older groups. This is probably due to differences between our studies. Falkenstein et al. used a younger age range, of 54 to 65 years, for their older group, and a time pressure to respond within 400 ms. Our study, however, used an older age range with no added time pressure.

Additionally, previous studies have explained that older adults (above 65 years), when presented with a task requiring a speed/accuracy trade-off, tend to be more cautious in responding accurately at the cost of speed (Brébion, 2001; Smith and Brewer, 1995). Thus, it seems plausible that the older adults would be more concerned about commission than omission errors. This, perhaps, explains why the older adults in our study, who were instructed to respond both quickly and accurately, had more omission errors, as compared to younger adults, due to their emphasis of accuracy at the expense of speed.

Moreover, there were more omission errors on the syllable, than the segment, task in the older group. Table 4 demonstrates the variability of omission errors in the older group on the syllable task. Only six out of the 16 older participants presented with more than seven omission errors (range: 7 to 22 errors). This suggests that although the older group had somewhat more difficulty making a syllabic, rather than segmental, Go/Nogo decision, the number of omission errors on the syllable task was highly variable. No apparent pattern of similarities, with regards to task order, task decision, gender, handedness, or background, amongst these participants (#70, 72, 73, 74, 78, and 89) was found to explain their high rate of errors on the syllable task.

4.2. Electrophysiological Data

4.2.1. N2d

Our behavioral RT data are consistent with our N2d electrophysiological data with regards to findings of between group differences and the lack of a within group difference on the segment and syllable tasks in the younger group. However, a within group task difference in the older group was apparent only in the electrophysiological data.

Foremost, our results revealed that a significant N2d (greater negativity for the Nogo compared to the Go stimulus) was found most prominently at fronto-central site Fz7, in both groups and on both tasks. This finding of a fronto-central N2d is consistent with Schmitt et al. (2000) and Schiller et al. (2003) using a similar Go/Nogo design. The younger group demonstrated the N2d effect at earlier time intervals, 301-450 ms on the segment task and 351-450 ms on the syllable task, although the earlier onset of the N2d in the segment task was not significant in a direct comparison of tasks. In contrast, the older group demonstrated the N2d effect later, at 401-500 ms on the segment task and 451-500 ms on the syllable task and a significant difference in access of segment earlier than syllable information was apparent.

The N2d latencies in both groups fall within the time window expected for language processing (Indefrey and Levelt, 2004; Levelt, 2001; Rodriguez-Fornells, Schmitt and Kutas, 2002; Schmitt et al., 2000, 2001). Moreover, the N2d latency (301-450 in the younger group, and 401-500 in the older group) occurs within the range wherein phonological encoding, specifically segmental and syllabic retrieval, should occur (300 to 500 ms) once word length is taken into account (Schiller, 2006). This suggests that the N2d effects reflect phonological encoding processes for speech production.

Our findings of later N2d latencies for the older adults could not be directly compared to other ERP studies using similar implicit naming tasks, since those studies focused solely on the young healthy adult population. Thus this study extends the field by establishing baseline latency data of N2d latencies on an implicit naming task in older adults. However, despite the lack of studies using this paradigm in the aging population, previous literature on ERP studies in aging and cognition, in general, points to latency delays in older adults, as compared to younger adults, on tasks that tap into cognitive processes known to decline with age, such as working memory or other cognitive processes that recruit the frontal lobe (Fabiani and Friedman, 1995; Friedman, Cycowicz & Gaeta, 2001; West, 2000).

Additionally, behavioral research has indicated phonological retrieval difficulties in speech production with age. Thus it was anticipated that older adults would present with later latencies on phonological tasks, as compared to younger adults (Abrams, et al., 2003; Burke, et al., 1991; Cross and Burke, 2004; Heine, et al., 1999; James and Burke, 2000; Rastle and Burke, 1996; White and Abrams, 2002). Our study extends the field and goes beyond the behavioral literature, as our data are at a level preceding the behavioral response and show the timing of access to this information. Thus, a delayed behavioral response could indicate a slowed motor response, but our data show there is slowing in access.

Consequently, findings from our study supports the TDH (Burke et al., 1991; James and Burke, 2000) that older adults have greater difficulty than younger adults in phonological retrieval for naming due to weakening of phonological links within the neural system with age. Results specify that although both segmental and syllabic retrieval are implicated, the syllabic level is more affected than the segmental level as the older group accessed segment information earlier than syllabic information. This would explain the increase of word-finding difficulties with age, as greater difficulty in accessing syllabic information halts the process of retrieving the corresponding phonetic syllabic codes from the mental syllabary, which is a necessary precursor to activate speech production (Levelt and Wheeldon, 1994). This finding was not predicted from the literature as findings from A.S. Brown (1991) indicated that syllabic information, rather than final segment information, is often most likely spontaneously available during a tip-of-the-tongue (TOT) state.

It still remains difficult to conclude from our data that the cause of the significant task difference in the older group is due to greater weakening of syllabic than segmental links within the phonological system. The reason is that observation of ERP data from the younger adults seems to indicate a similar pattern, namely an earlier N2d start for the segment than for the syllable task, even though a direct comparison was not significant ($p=0.409$). Observation of the individual N2d amplitude data for both the younger and older participants on the segment task in Figure 26, and on the syllable task in Figure 27 a and b, indicate great variability among both groups. This might explain why although a comparable 50-ms latency task difference was found in each group, it was significant in only the older and not the younger group. Taking variability into account is important in considering the overall time course in processing for each group. Perhaps more power is necessary to uncover this difference in the younger group. Furthermore, since the time windows for statistical analysis was 50 ms, it might be that the task difference in the younger group was not detected. Finer analyses with narrower time bins might uncover a within group difference, which will be pursued in future analyses.

One may argue that the reason behind the significant syllabic vs. segmental latency difference within the older group might be due to inherent task biases; namely, that the syllable task was more difficult than the segment task. However, given our behavioral findings of a lack of significant task differences within each group on RT along with comparable P3d task latency in each group, it is appears that task difficulty was comparable within each group. Thus, it is not likely that N2d processing differences were due to task set-up biases but rather to phonological processing differences.

Alternatively, one might explain that the latency differences noted in the older group were due to overall cognitive slowing with aging, rather than a phonological processing deficit, as proposed in the TDH. To address this concern, an investigation of the P3d, an index of cognitive effort and task demand, is necessary. P3d latency data, however, does not substantiate this account (see the P3d section below for a more detailed discussion).

Moreover, an explanation of the significant N2d latency delays in the older population might be due to differences in inhibitory processing with age, rather than task specific phonological processing. Prior developmental research has suggested that inhibitory ability functions in an inverted U-shaped function with age. Specifically, intermediate-aged adults are better at inhibiting responses than both children and older adults (Dustman, Emmerson, and Shearer, 1996). Thus, in the child and adolescent population, N2 latency decreases with age (Johnstone, Pleffer, Barry, Clarke, and Smith, 2005; Jonkman Lansbergen, and Stauder, 2003; Lamm, Zelazo, and Lewis, 2006), while in the adult population N2 latencies increase with age (Schroeder, Lipton, and Ritter, 1995).

In fact, Falkenstein et al. (2002) directly compared N2 and P3 latencies in the young (mean age: 22.5 years) and old (mean age: 58.3 years) adult population, using a simple visual Go/Nogo task, e.g. letters K and T. They suggested that N2 reflects modality-specific inhibition while P3 reflects a general non-specific inhibition. Results revealed a 25 ms delay in the visual N2d, and an approximately 35 ms delay in the Go and Nogo-P3, in their older compared to younger participants. Our findings showed a 100 ms N2d delay yet apparently comparable P3d latency, in our older (mean age: 73.3 years), as compared to younger (mean age: 28.3 years) group. This suggests that the inhibition delays in the older adults were related more to modality specific phonological processing rather than to general inhibition processing delays, especially as the delays were considerably above the 25 ms delays noted in the older group in the Falkenstein et al. (2002) study. However, without a control inhibition study in the above 65 year old population, we cannot fully rule-out the extent of inhibition vs. phonological contributions seen in the N2d delays in our study. Thus, a follow-up study of a simple Go/Nogo task with the above 65 year old population should be pursued.

The phonological processing results from our study further provided insight into the time course of processing for phonological encoding in the normal process of lexical retrieval for speech production. A common criticism against internal monitoring studies is that they do not reflect production processes, but rather meta-linguistic retrieval or perception processes in the sense that the participant retrieves and produces the item and then perceives what he/she has produced. Previous literature, however, has established that this is not likely the case. This is based on findings from Wheeldon and Levelt (1995) and Schiller (2006) which indicate that latencies of encoding of later segments or metrical stress is relatively more delayed than encoding of segments or metrical stress that is closer to the beginning of the word. This data reflects features of the speech production, rather than the perception, system

Thus, based on these previous findings, we can interpret our data as reflecting time-course of retrieval of phonological sublevel information, and examine how age impacts this process. Previous research has proposed that segmental and metrical retrieval occurs in parallel and in an incremental fashion (Levelt et al., 1999; Roelofs and Meyer, 1998). Additionally, evidence from Schiller et al. (2003) suggests that metrical retrieval, specifically, stress and syllabic information, proceeds in parallel (Schiller et al., 2003). Data from the younger group seems to support the finding of parallel processing within phonological encoding, as the very small difference (less than 50 ms) in access of segmental and prosodic information seems to indicate that they are independent from each other and roughly parallel.

Data from the older group, however, indicated that retrieval of segmental information precedes that of syllabic information by roughly 100 ms, which was more than that found for the younger group. This does not indicate that the processes are not “parallel” in the sense of being independent, of course. Rather, it seems unlikely that the output of the segmental process feeds in as the input of the prosodic process given the findings with the younger group. Our findings do suggest that aging affected syllabic access more adversely than segmental access.

4.2.2. P3d

We observed the P3d as a large positivity following the N2d in both groups and on both tasks at around 601 to 950 ms, most prominently at site Fz7. This topography is consistent with previous inhibition studies (Schiller et al., 2003) and reportedly reflects general inhibition related to cognitive effort. This has been suggested in studies using monkeys (Gemba and Sasaki, 1989) and in humans (Kopp, Mattler, and Goertz, 1996; Kiefer et al., 1998).

Data revealed that the P3d effect was not significantly different between tasks in each group, indicating that both tasks were comparable with regards to task demands. This supports the RT data of comparable latencies for the tasks within each group.

The RT response occurred during the P3d, which makes interpretation of the P3d more complicated. De Jong et al. (1990) similarly reported that their P3 onset corresponded with RT in their stop-signal task. They suggested that this finding supports the view that the P3d reflects general inhibition acting on central response activation processing. Kok, Ramautar, de Ruiter, Band, and Ridderinkhof (2004), added to this account in their study using dipole source modeling, in proposing that this processing was in or near the motor and pre-motor cortices. However, a methodological control, e.g. time-locking the ERPs to RT, would allow for a better account of the P3d latency across groups in our data. This timelocking to the RT will be pursued in a future analysis.

A within-group difference was noted in the morphology of the waveform in the younger group. Findings revealed a two-peaked P3d waveform on the syllable, and not on the segment task. This two-peaked morphology only on the syllable task, likely reflects modulation of processing speed in making a two- vs. one-syllable decision. The obvious explanation for this P3d peak difference is that word length for the one- vs. two-syllable stimuli lists in the syllable decision were different (t (25)=2.0595, p=.0000) and therefore processing for two-syllabic words would take longer than processing for one-syllabic words. A word length effect, however, was not seen in the final /n/ vs. /r/ lists used for the segmental decision task (t (24) = 2.0639, p=.0747). Thus, two-peaks were not found in the segment task. This was even though the segmental lists were comparable to the syllable lists in their inclusion of an equal number of the stimuli with one-syllable words and two-syllable words. Appendix E lists the stimuli for each task.

There was also a significant difference between groups only on the segment task at times 851-950 ms, indicating that the older group experienced greater cognitive load, as compared to younger adults, only on the segment task. This significant difference was apparent from looking at the difference waves, however, statistical analysis, using post-hoc Tukey testing, did not find a significant group difference on the segment task. This is probably due to the high P3d variability, particularly among the older participants. Figure 23 shows statistical graphs of the P3d effect with large standard error bars, illustrating the large variance

Figure 28 shows a plot of the individual P3d peak amplitude of the younger and older participants on the segment task at times 751-950 ms, where the observed difference was apparent. Results show that there was great variability in peak P3d amplitude at times 751-950 ms, particularly among the older participants (approximately seven older participants (E72, 74, 75, 76, 82, 86, 89) and one younger participant (Y44). These participants presented with “outlier” P3d data (greater than 5 µV or less than -5 µV from 751-950 ms), in two or more time intervals when using both the younger group mean and SD, as the reference point. This greater positive amplitude in the older, than the younger, group was apparent on both Go and Nogo trial; the subtraction waveform losses this difference. This may indicate that the older group was working harder for both trial types. Future statistical analyses using a Stimulus (Go, Nogo) x Group (Younger, Older) x Time (seven time intervals from 601-950 ms) for each task separately should be conducted, to investigate group differences by trial.

Additionally, there was a group difference with regards to the length of the P3d effect; in the older, as compared to the younger, group the P3d lasted longer on the segment task (200 ms), although onset of the P3d across groups and tasks was comparable. The longer processing time on the segment task, as compared to the syllable task, is probably due to the fact that a syllabic decision (one vs. two-syllable—a task where one knows there will only be at most two syllables) can be made even before the full word is phonologically encoded, while a final segment decision cannot. That is, in making a syllabic decision, once the initial segment of the second syllable is retrieved, the participant already knows that the target word contains two-syllables. However, full phonological encoding must be done in order to make a final segment decision. This greater cognitive workload, particularly on the segment task, was reflected in the P3d group difference on the segment task.

4.2.3. VEPs

VEPs have been reported in the literature as a series of peaks reflecting visual processing (Odom et al., 2004). These ERP components were observed at fronto-central sites as a negative peak around 100 ms (N1) and a positive peak at around 200 ms (P2) which are largest at central occipital site (Oz) with inversion at fronto-central sites. Findings revealed comparable visual processing latencies in both groups rejecting the theory of generalized slowing and sensory delays with age (Kline and Schieber, 1985). Thus, later N2d delays in the older group cannot be attributed to earlier visual processing delays, but rather to stage-specific or localized phonological slowing with age.

However, the greater VEP amplitude at time 201-250 ms, in the older, as compared to the younger, group, demonstrates that greater visual attention was needed. This might reflect the fact that the older participants focused and attended better to the given tasks.

5. Conclusion

Results of this study indicated a later N2d latency on the segmental and syllabic phonological tasks in the older, compared to the younger, group. In particular, within the older group, retrieval of syllabic information was significantly later than retrieval of segmental information. These findings support the TDH that there are age effects at the phonological level of processing. This study further suggests that the phonological breakdown is greater at the syllabic, than segmental, level.

Additionally, P3d findings revealed no significant task difference within each group. A significant group difference was found only on the segment task. This indicates that the older, as compared to the younger, group experienced greater cognitive load in performing the segment task. In general, however, older participants had greater P3 positivity for both go and nogo trials than the younger group. This may indicate that the older group was working harder for both trial types.

VEP findings revealed comparable latencies both between and within groups. Thus, the data suggests that phonological processing delays in the older group, as reflected in later N2d and P3d components, were not due to early visual processing delays, but rather to stage-specific phonological processing deficits, as per the TDH.

Findings from this study also support the parallel view of processing for the two phonological substages of segment and syllable information in the younger adults. It is probably also parallel in the older adults, although the data showed that syllabic access is affected more by aging than segmental access. Overall, the change in phonological processing with age is consistent with the TDH.

Implications of the study are that healthy older adults might benefit from particular practice with phonological tasks, mainly of syllabic information, to improve retrieval. Future studies should investigate the effects of phonological practice in improving word retrieval in aging. Additionally, age affects on other sublevels of phonological processing, e.g. metrics, syllabification (as per Levelt et al., 1999) should be conducted.

Moreover, ERP investigations of naming problems should extend to the brain-damaged population, as well, e.g. anomia, apraxia. Results of this study can serve as an age-matched control for investigation of phonological retrieval deficits in the brain-damaged population. Studies focused on therapeutic remediation at the appropriate level of difficulty and investigation of effects of post-treatment changes in brain processing of the brain-damaged population should follow.

Table 1

Group size (N), gender, mean age (standard deviation), and self-report of handedness and experience of tip-of-the-tongue (TOT) states among participants

Group	N	Gender	Age	Handedness	TOT Experience
Younger	16	7 M, 9 F	28.3 (4.9)	14 Right-handed 2 Left-handed	13 No problem 1 Occasionally 2 No data
Older	16	5 M, 11 F	73.3 (3.3)	12 Right-handed 3 Left-handed 1 ambidextrous	9 No problem 4 Occasionally 2 No data

Table 2

Mean reaction time (standard deviation) in milliseconds on the Segment and Syllable tasks

Group	Segment RT	Syllable RT
Younger	663 (81)	665 (110)
Older	759 (90)	771 (90)

Table 3

Overall mean (standard deviation) number of Omission and Commission errors (out of 140 possible trials) in each Group (Younger vs. Older) and on each Task (Segment vs. Syllable)

Type of Error	Younger	Older	Segment Task	Syllable Task
Omission	1.7 (2.2)	4.9 (5.3)	1.9 (1.8)	4.7 (5.6)
Commission	1.3 (2.2)	2.0 (3.6)	1.5 (3.3)	1.8 (2.7)

Table 4

Groups mean (standard deviation) number of Omission and Commission errors (out of 140 possible trials) on Segment and Syllable tasks

Group	Omissions: Segment	Omissions: Syllable	Commissions: Segment	Commissions: Syllable
Younger	1.2 (1.3)	2.1 (2.8)	1.4 (2.3)	1.2 (2.2)
Older	2.6 (1.9)	7.2 (6.5)	1.6 (4.2)	2.3 (3.1)

Table 5

N2d Response x Site ANOVA at given Time intervals on each Task (Segment, Syllable). Note: only main effect of Response and interaction of Response x Site are reported because only these cases indicate the presences of the N2d. All effects were significant at site Fz7. η2=effect size can be interpreted as large (.2), medium (.09) and small (.01). Note: *=statistical findings in these time intervals do not reflect an N2d effect, rather the onset of a P3d effect.

Group	Task	Time (ms)	Factor	F	*p*	η2
Younger	Segment	301-350	Response	6.193	0.025	0.292
		351-400	Response	12.433	0.003	0.453
		401-450	Response	8.379	0.011	0.358
	Syllable	351-400	Response x Site	5.746	0.012	0.277
		401-450	Response x Site	4.460	0.023	0.229
		551-600*	Response	7.363	0.016	0.329
			Response x Site	4.676	0.024	0.238
Older	Segment	401-450	Response x Site	7.568	0.009	0.335
		451-500	Response x Site	8.801	0.006	0.370
		501-550*	Response x Site	4.290	0.048	0.222
	Syllable	451-500	Response x Site	7.228	0.012	0.325
		501-550*	Response x Site	7.445	0.013	0.332
		551-600*	Response x Site	6.472	0.019	0.301

Table 6

N2d latency (milliseconds) on the Segment and Syllable tasks for the two groups

Group	Segment latency	Syllable latency
Younger	301-450	351-450
Older	401-500	451-500

Table 7

P3d Response x Site ANOVA at given Time intervals on each Task (Segment, Syllable) for the Younger group. Note: only main effect of Response and interaction of Response x Site are reported because only these cases indicate the presences of the P3d. η2=effect size can be interpreted as large (.2), medium (.09) and small (.01).

Note: All effects were significant at site Fz7.

*=statistical findings in these time intervals reveal a P3d effect at sites Fz7 and Fz

**= statistical findings in this time interval reveal a P3d effect only at site Fz7

Group	Task	Time (ms)	Factor	F	*p*	η2
Younger	Segment	601-650	Response	11.531	0.004	0.435
		651-700	Response	12.413	0.003	0.453
		701-750	Response	5.154	0.038	0.256
	Syllable	601-650	Response	8.952	0.009	0.374
			Response x Site	7.257	0.006	0.326
		651-700	Response	5.086	0.040	0.253
			Response x Site	7.451	0.006	0.332
		701-750*	Response x Site	4.241	0.039	0.220
		901-950*	Response x Site	3.766	0.053	0.201
		951-1000**	Response x Site	4.076	0.054	0.214

Table 8

P3d Response x Site ANOVA at given Time intervals on each Task (Segment, Syllable) for the Older group. Note: only main effect of Response and interaction of Response x Site are reported because only these cases indicate the presences of the P3d. η2=effect size can be interpreted as large (.2), medium (.09) and small (.01).

Note: All effects were significant at site Fz7.

Group	Task	Time (ms)	Factor	F	*p*	η2
Older	Segment	601-650	Response	5.817	0.029	0.279
		651-700	Response	8.793	0.010	0.370
		701-750	Response	7.932	0.013	0.346
		751-800	Response	5.351	0.035	0.263
		801-850	Response	6.251	0.024	0.431
		851-900	Response	4.589	0.049	0.234
		901-950	Response	7.076	0.018	0.321
	Syllable	601-650	Response	6.859	0.019	0.314
			Response x Site	4.250	0.049	0.221
		651-700	Response	10.78	0.005	0.418
		701-750	Response	11.320	0.004	0.430
		751-800	Response	6.287	0.024	0.295

Table 9

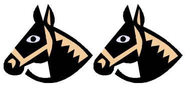
P3d latency (milliseconds) on the Segment and Syllable tasks for the two groups

Group	Segment latency	Syllable latency
Younger	601-750	601-750 and 901-1000
Older	601-950	601-800

Figure 1

Lexical Access Model of Speech Production

Picture:



Stage 1: Conceptual/semantic and syntactic processing

Concept:	[horses]
Semantic and Syntactic elements:	‘horses’=animal, has a tail, mane, etc.; plural noun

Stage 2: Phonological processing

Morpheme:	horse + s
Sound segments:	/h/ />/ /r/ /s/ /I/ /z/
Syllable and stress:	/h>r/ /sIz/, two syllables, initial syllable stress
Combined:	[h>r]’ [sIz]
Phonetic code:	[h>r]-[sIz]
Articulation:	“horses”

Figure 2

A) Raw N200 Nogo and Go waves as demonstrated in the grand average (GAV) data from younger participants on the segment task.

B) N2d effect (Nogo minus Go waves) in the GAV data from the younger participants on both tasks.

x-axis=time (ms); y-axis=amplitude (μV)

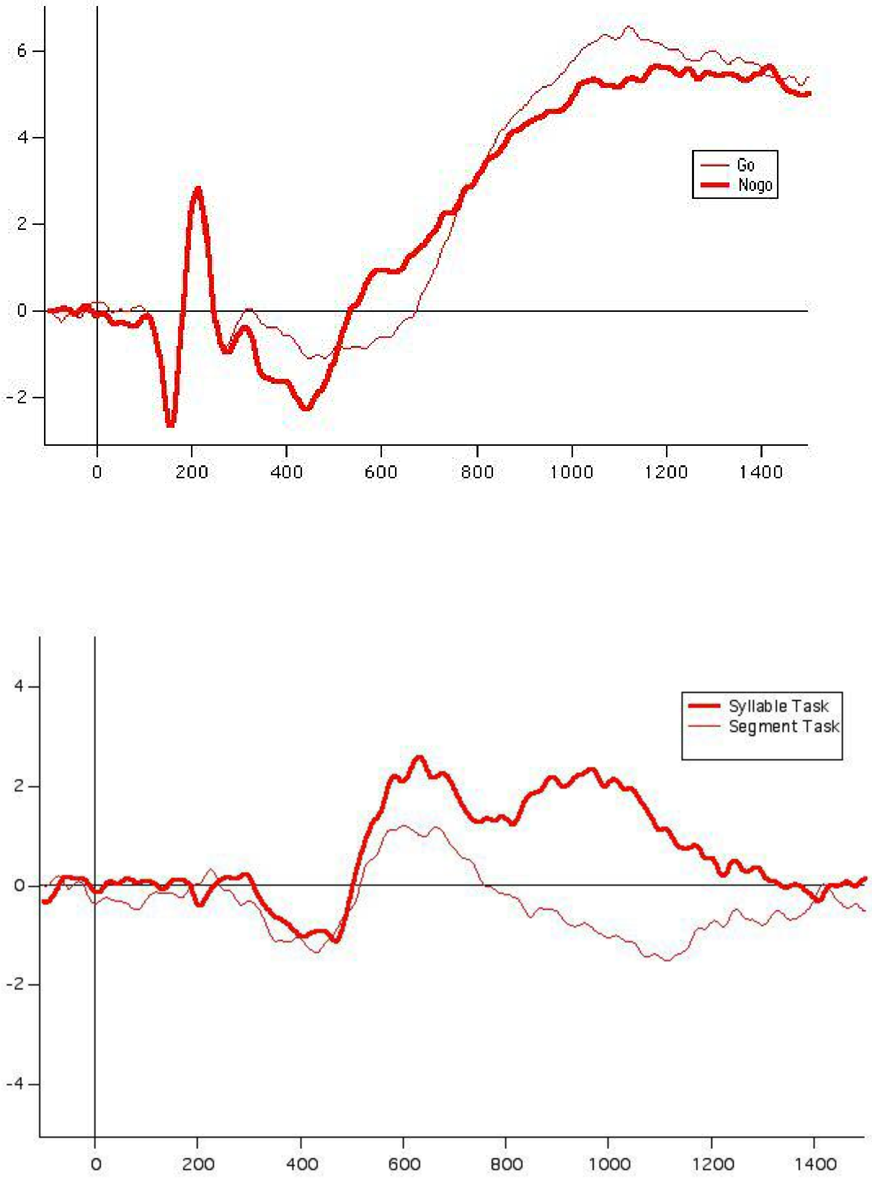
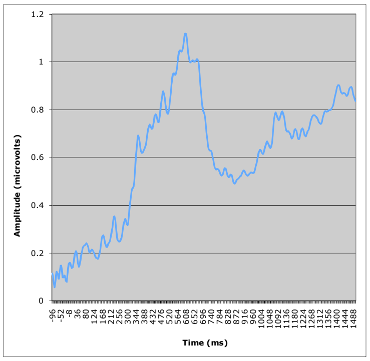


Figure 3

Global Field Power (GFP) Graphs of grand average (GAV) difference wave data for the younger participants in each condition A) segment and B) syllable. The earliest and latest time points (trough to trough) around the N2d peak is seen as a very steeply sloping region of the GFP plot. This time range was set as the start and end points of the N2d. Observation of the raw data corroborated the selection of 251-600 ms as the N2d time range chosen for further statistical analysis. The following peak was P3d.

A) Segment Task:



B) Syllable Task:

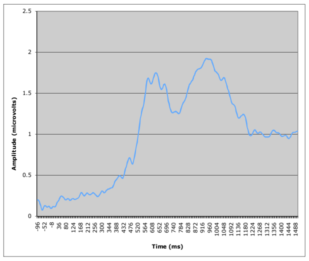
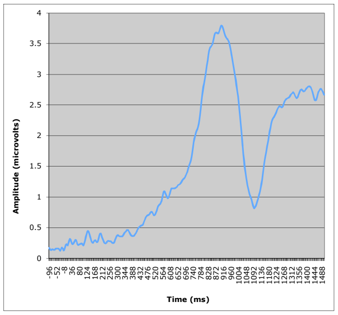


Figure 4

Global Field Power (GFP) Graphs of grand average (GAV) difference wave data for the older participants in each condition A) segment and B) syllable. The earliest and latest time points (trough to trough) around the N2d peak is seen as a very steeply sloping region of the GFP plot. This time range was set as the start and end points of the N2d. Observation of the raw data corroborated the selection of 251-600 ms as the N2d time range chosen for further statistical analysis. The following peak was P3d.

A) Segment Task:



B) Syllable Task:

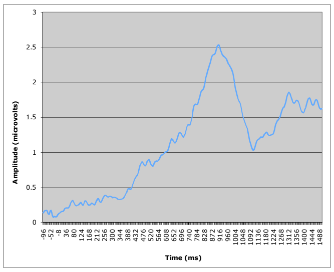
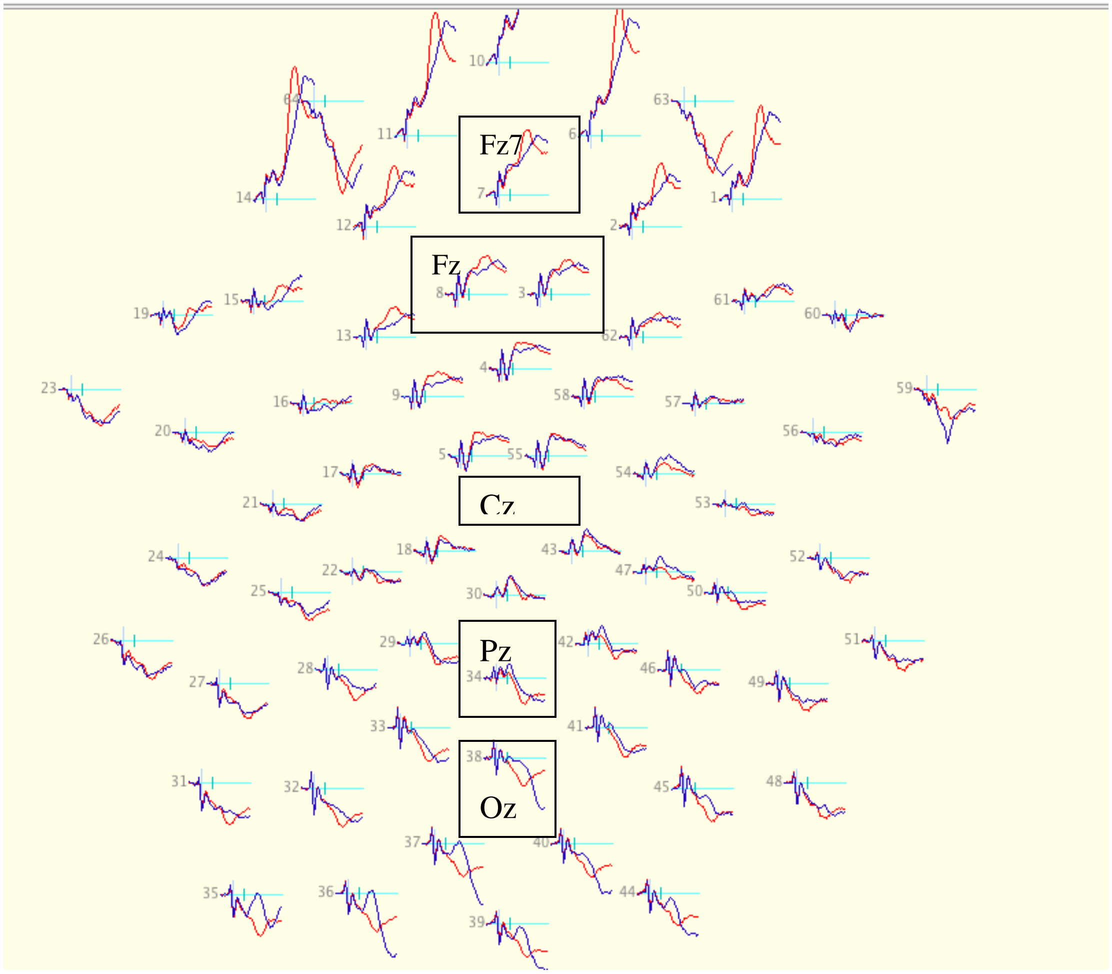


Figure 5

Display of 65 electrodes with sites of interest, Fz7, Fz, Cz (reference), Pz and Oz (from front to back), boxed. Blue=Go waves; Red=Nogo waves.

FRONT of head



BACK of head

Figure 6

P3d effect (Nogo minus go waves) (between 600-1100 ms) as demonstrated in the grand average (GAV) data from both groups on the segment task.

x-axis=time (ms); y-axis=amplitude (μV)

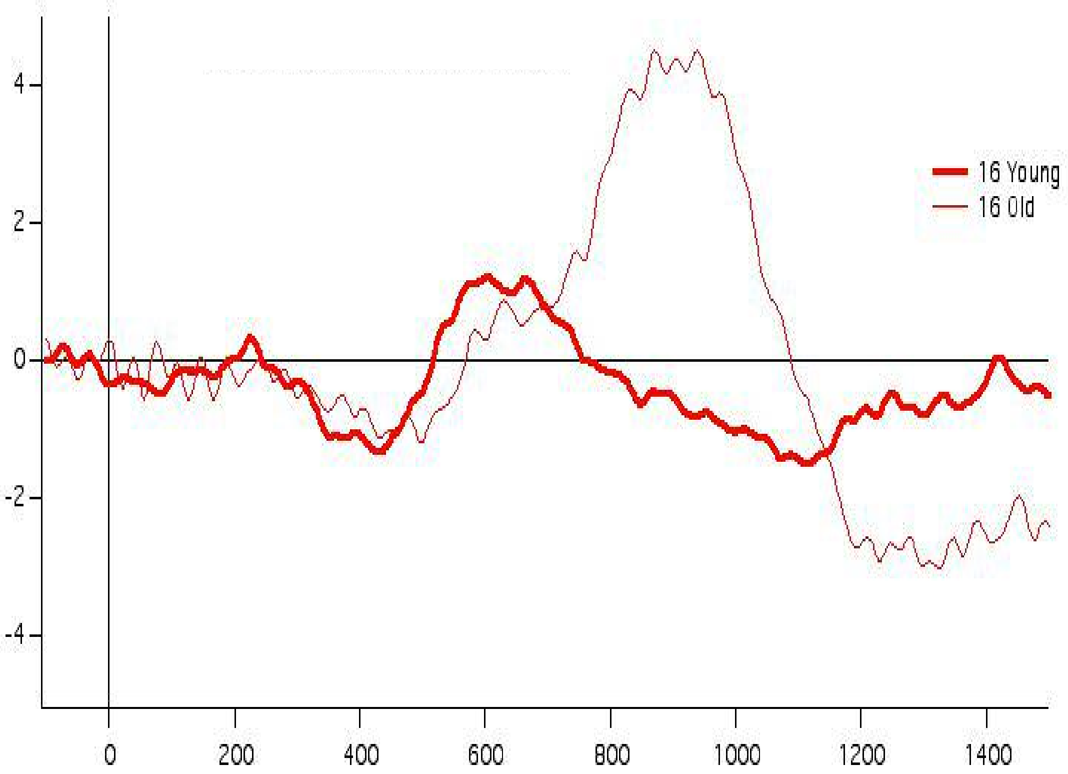


Figure 7

Chart of Omission Errors in the Younger and Older groups on the Syllable task

The younger group had a mean (SD) of 2.1 (2.8) omission errors (range: 0-11), while the older group had 7.2 (6.5) omission errors (range: 1-22). Overall, the older group had significantly more omission errors than the younger group and particularly these errors were noted on the syllable, rather than the segment, task with great variability.

Younger group: 1/16 participants had more than seven errors

Older group: 6/16 participants had more than seven errors

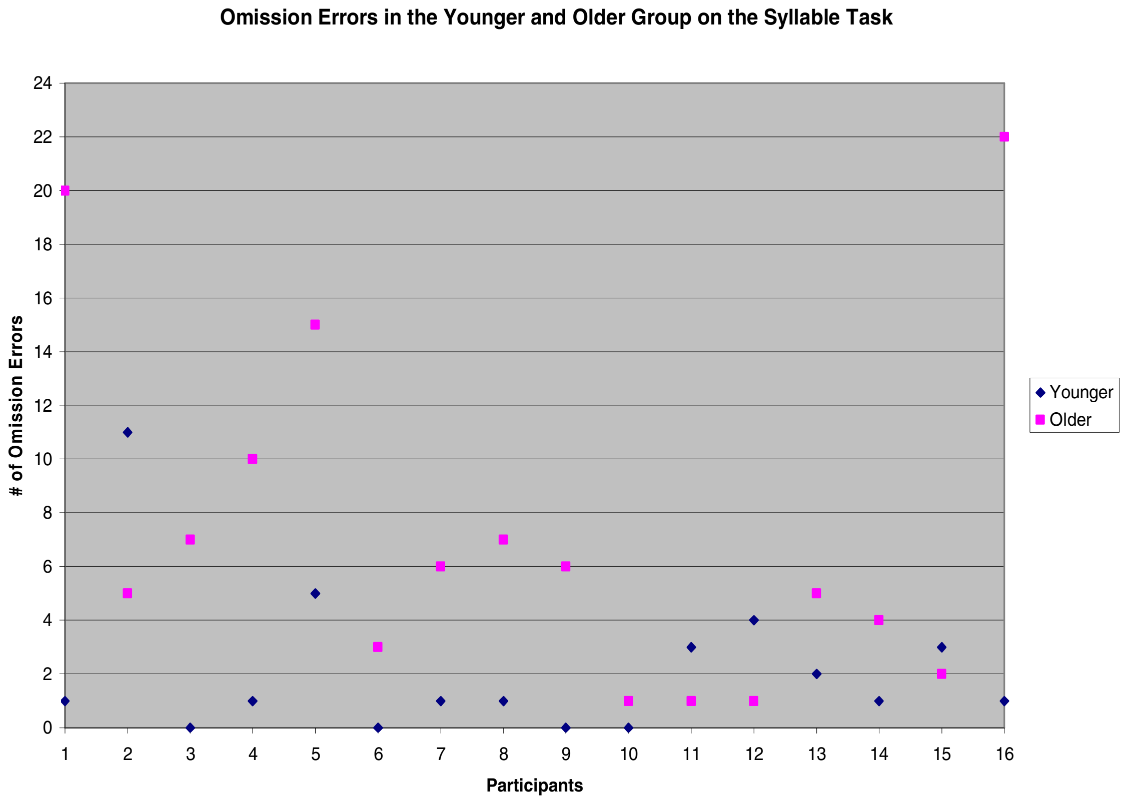


Figure 8A

Topographical Maps of N2d at Frontal Sites in Younger Participants on the Segment task. Time frames increase in 20 ms increments from 312-452 ms. The N2d appears as blue in frontal regions and is significant throughout this time range. Scale: approximately 0.20 µV/step.

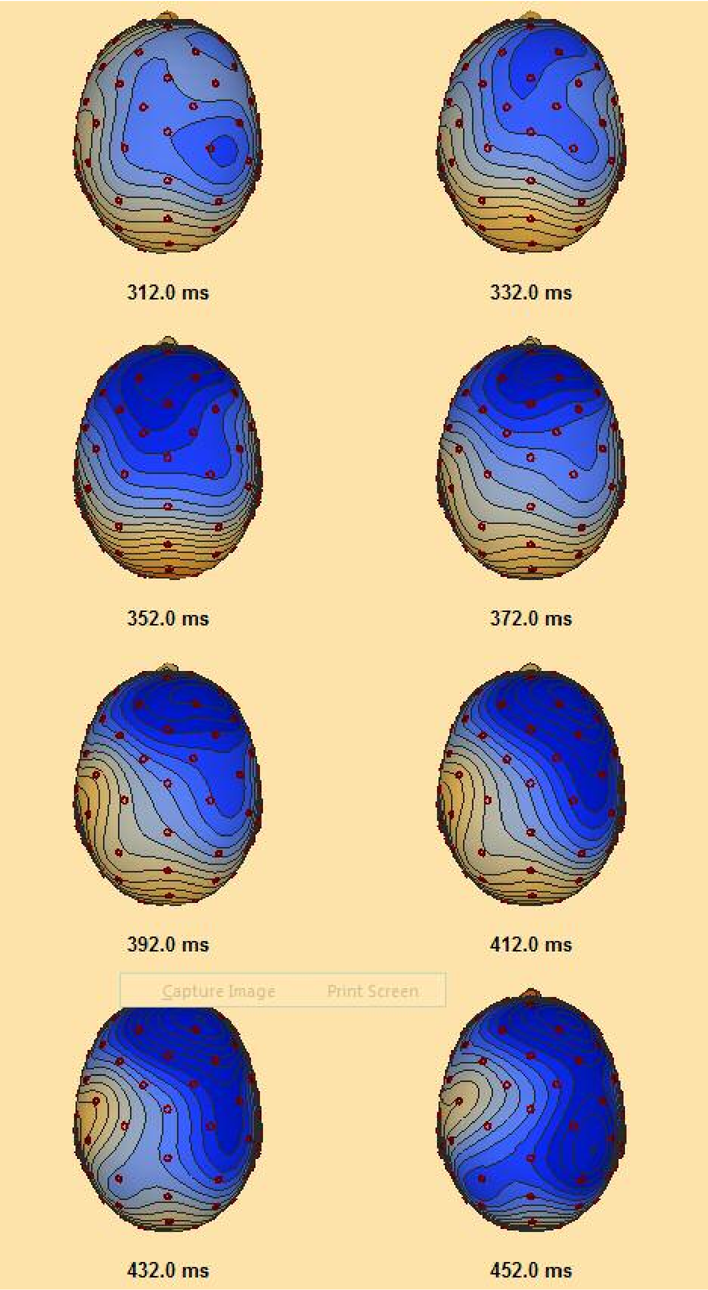


Figure 8B
Topographical Maps of N2d at Frontal Sites in Younger Participants on the Syllable tasks. Time frames increase in 20 ms increments from 352-452 ms. The N2d is largest, appears as blue, in frontal regions at around 392-452 ms. Scale: approximately 0.20 μV/step.

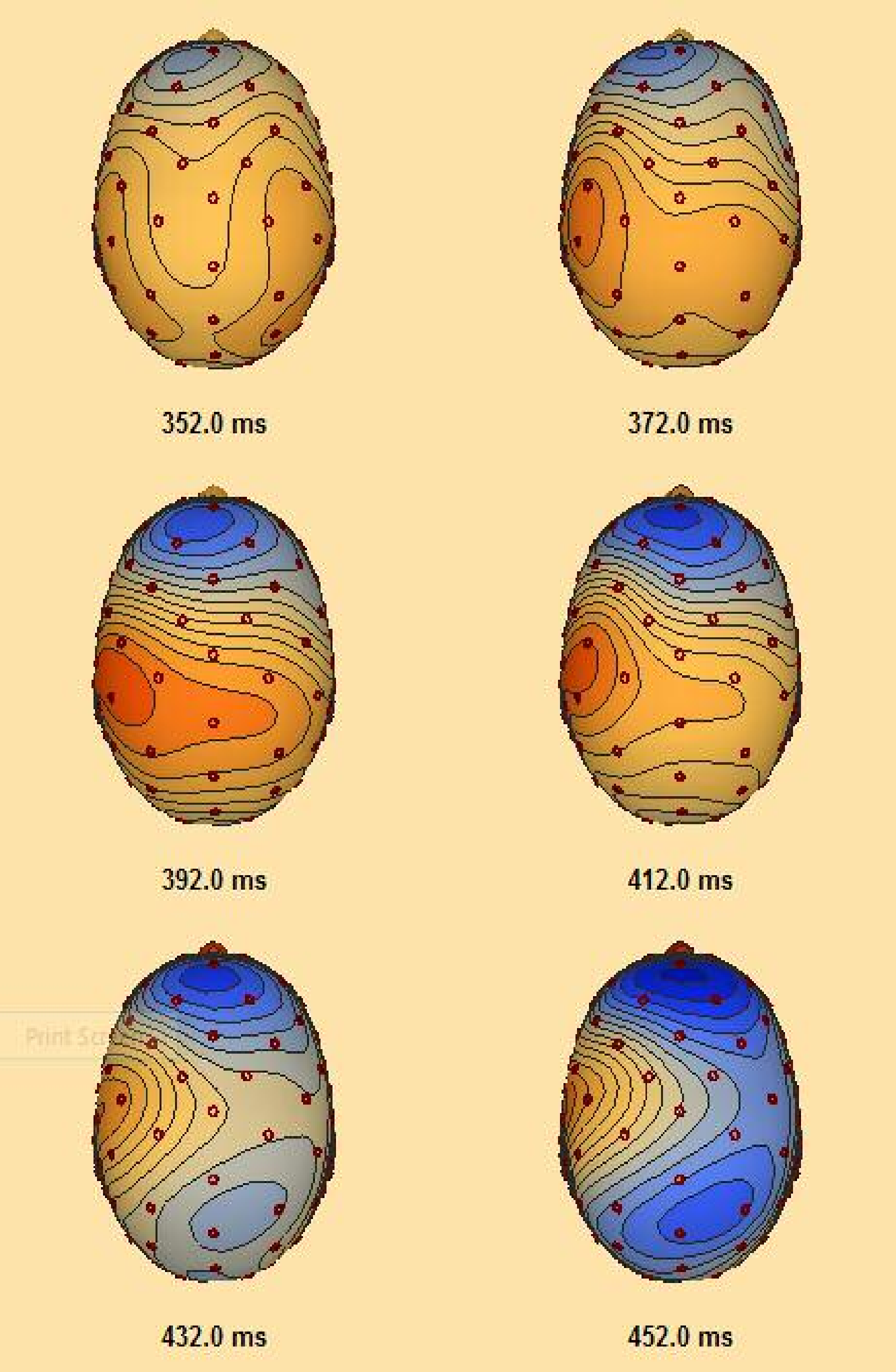


Figure 8C

Topographical Maps of N2d at Frontal Sites in Older Participants on the Segment task. Time frames increase in 5 ms increments from 400-500 ms. The N2d is largest, appears as blue, in frontal regions at around 435-500 ms. Note inversion (i.e. positivity, red) at mastoids. Scale: approximately 0.20 µV/step.

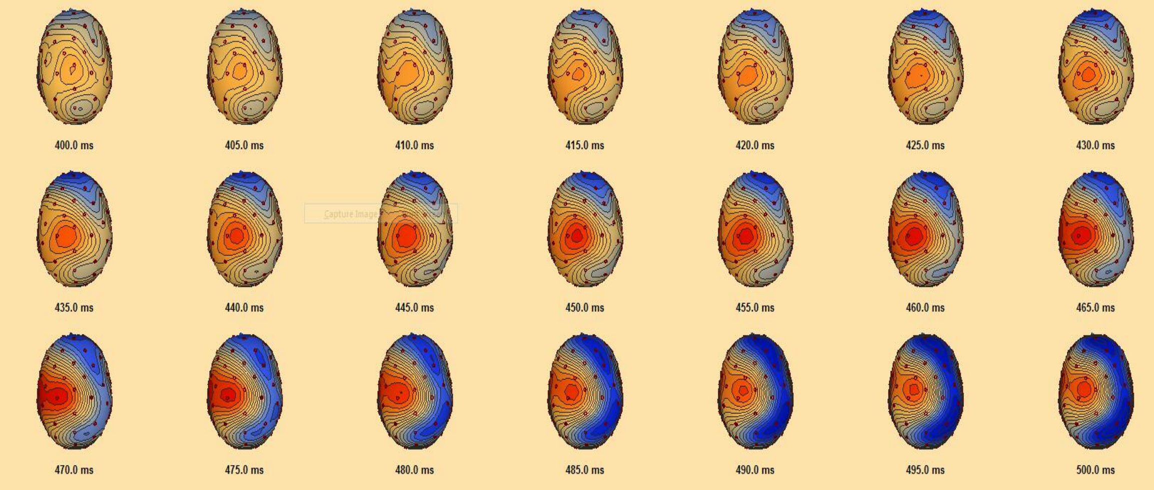


Figure 8D

Topographical Maps of N2d at Frontal Sites in Older Participants on the Syllable task. Time frames increase in 5 ms increments from 453-508 ms. The N2d appears as blue in frontal regions and is significant throughout the entire time range. Note inversion (i.e. positivity in red) at mastoids. Scale: approximately 0.20 µV/step.

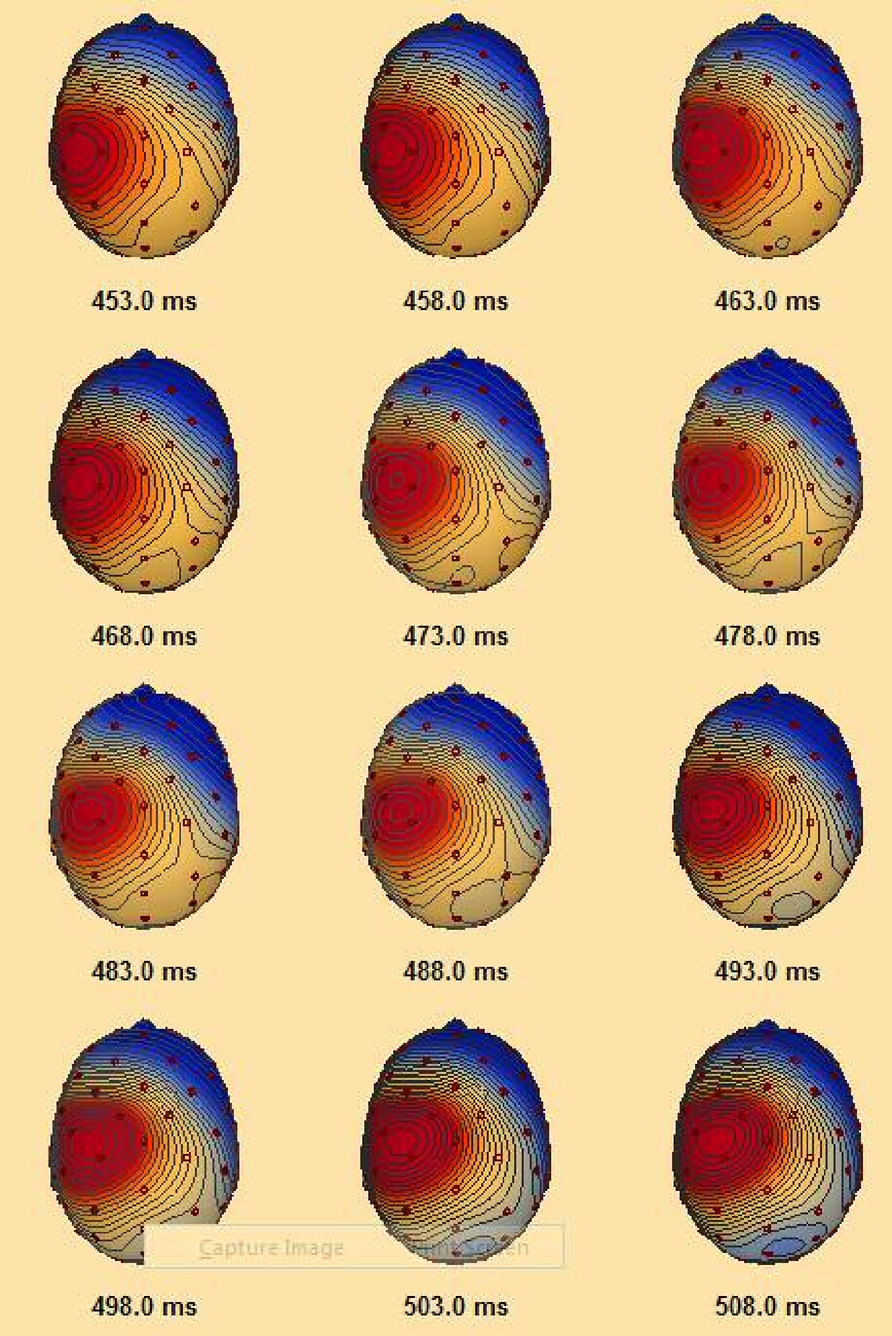
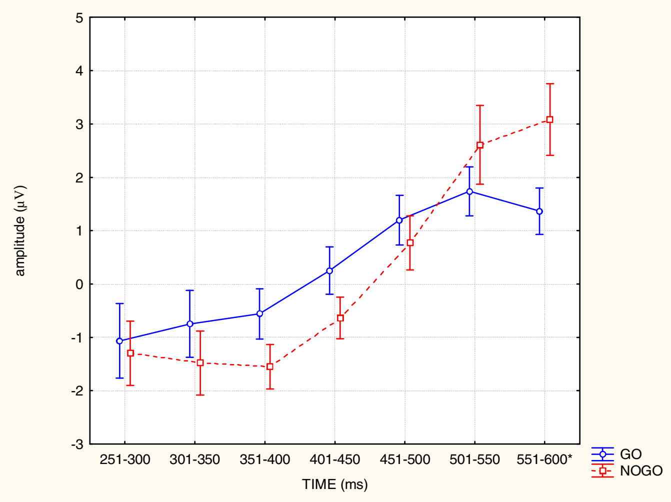


Figure 9
N200 Response X Time interaction in the Younger group on the A) Segment and B) Syllable tasks. Post-hoc testing revealed a significant response at later time intervals, namely, 551-600 ms on the segment task, and 501-600 ms on the syllable task. Observation of the graphs, however, reveals that this response really reflects the onset of the P300, not the N200, as the Nogo trials had a larger positivity than the Go trials.

Note: Vertical bars denote +/- standard errors

A) Segment Task:



B) Syllable Task:

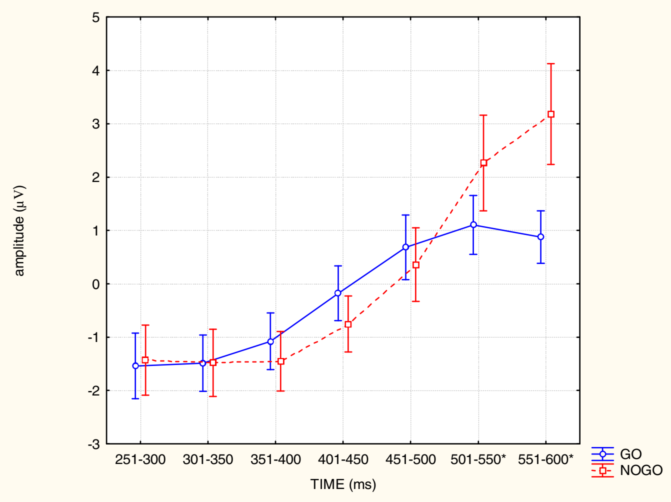


Figure 10

N200 Response X Time interaction in the Older group on the Syllable task

Post-hoc testing revealed a significant response only at later time intervals 551-600 ms. Observation of the graph, however, reveals that this response really reflects the onset of the P300, not the N200, as the Nogo trials had a larger positivity than the Go trials.

Note: Vertical bars denote +/- standard errors

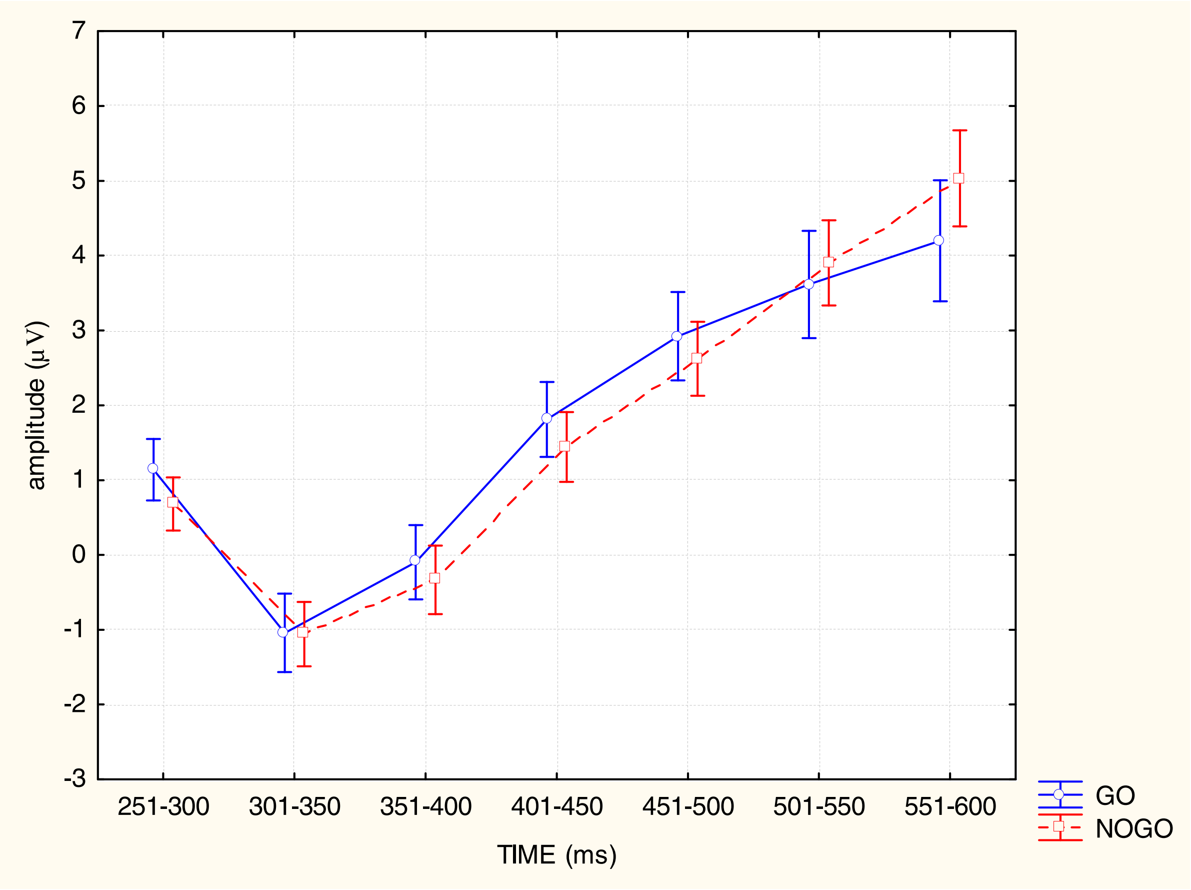
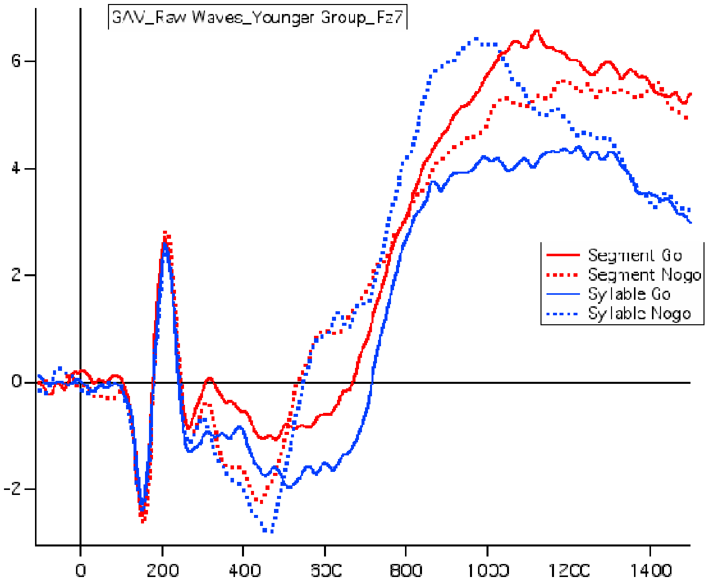


Figure 11

Task comparison of GAV raw Go and Nogo N200 and P300 waves at site Fz7 in the Younger and Older group. Results revealed that the N200 (negative peak between 251-600 ms) occurs 50-ms earlier for the segment than syllable task, while the P300 (positive peak between 601-1100 ms) occurs at approximately the same time for the tasks, in both groups. x-axis=time (ms); y-axis=amplitude (μV)

A) Younger Group:



B) Older Group:

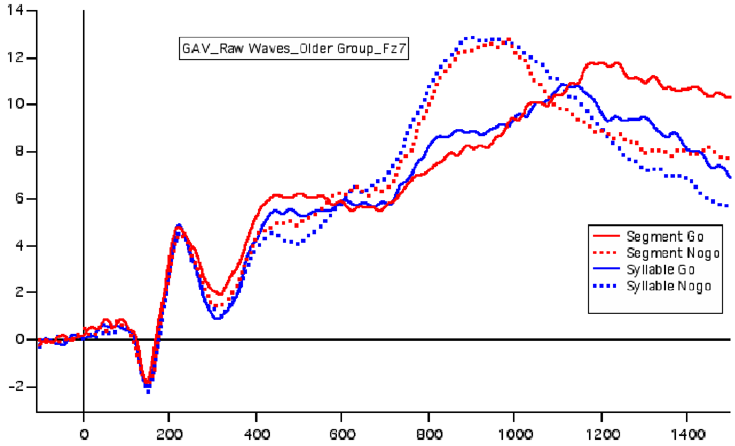
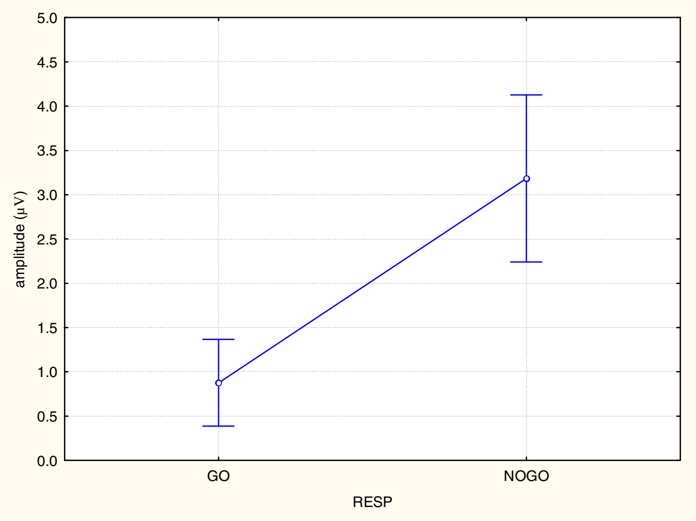


Figure 12

N200 Statistical Analysis: A) Main effect of Response and B) Response X Site interaction at time 551-600 ms in the Younger group on the Syllable task

Observation of the graphs, however, reveals that the significant effect at this later time interval really reflects the onset of the P300 as the Nogo trials are more positive than the Go trials. Note: Vertical bars denote +/- standard errors

A) Main effect of Response:



B) Response X Site interaction:

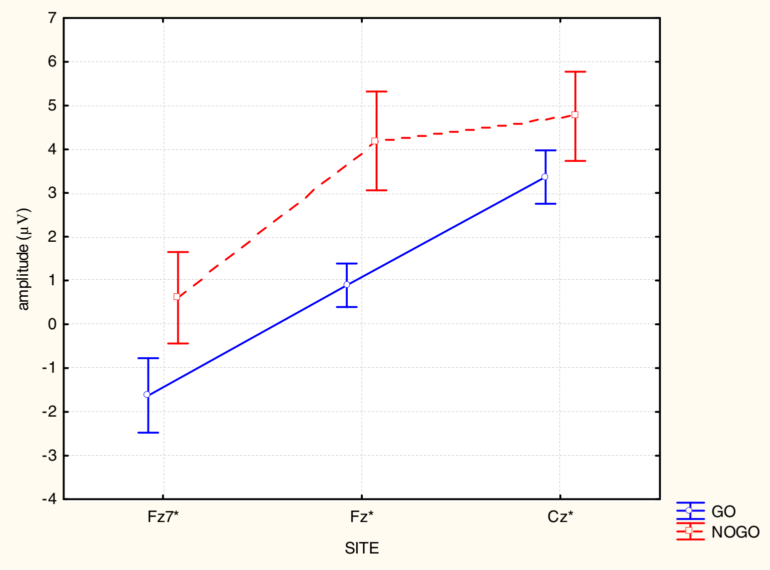
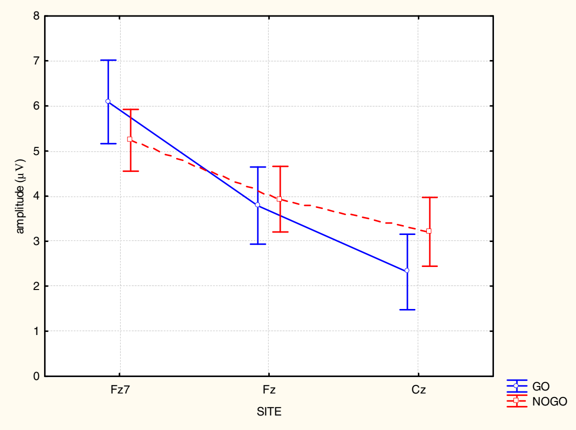


Figure 13

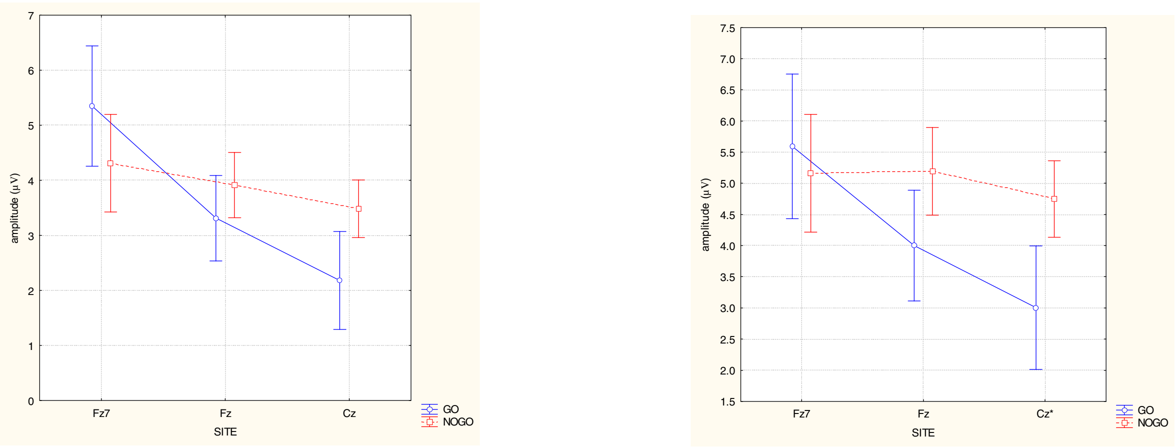
N200 Statistical Analysis: Response X Site interactions in the Older group for the A) Segment and B) Syllable tasks at times 501-550 ms and 551-600 ms. Post-hoc testing, however, did not reveal a particular site where the N200 was significant. Furthermore, observation of the graphs reveal that at site Fz and Cz the effects do not reflect an N200 response but rather a P300, as the Nogo trials were more positive than the Go trials.

Note: Vertical bars denote +/- standard errors

A) Segment task at 501-550 ms:



B) Syllable task at:


501-550 ms:

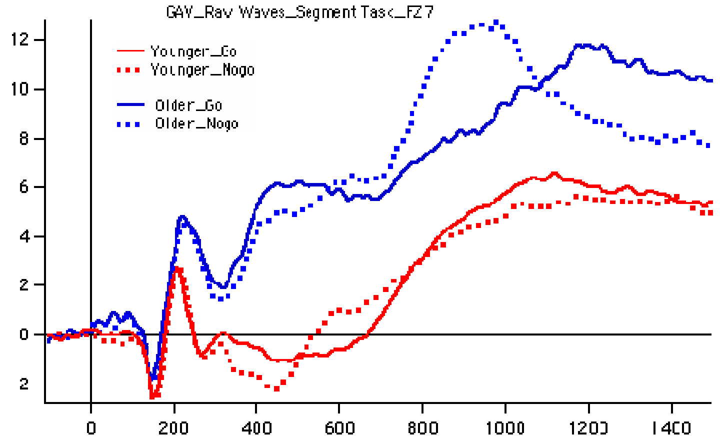
551-600 ms:

Figure 14

Group comparison of GAV raw Go and Nogo N200 (negative peak between 251-600 ms) and P300 (positive peak between 601-1100 ms) waves at site Fz7 on the A) Segment and B) Syllable tasks. Results revealed that the N200 appears to begin 100 ms later in the older as compared to the younger group on both tasks. The P300 appears to last for a longer time in the older, than the younger, group on the segment task (200 ms longer), although the P3d onset is comparable across groups and tasks. Additionally, the younger participants demonstrate a two-peak P3d effect on the syllable task.

x-axis=time (ms); y-axis=amplitude (µV)

A) Segment Task:



B) Syllable Task:

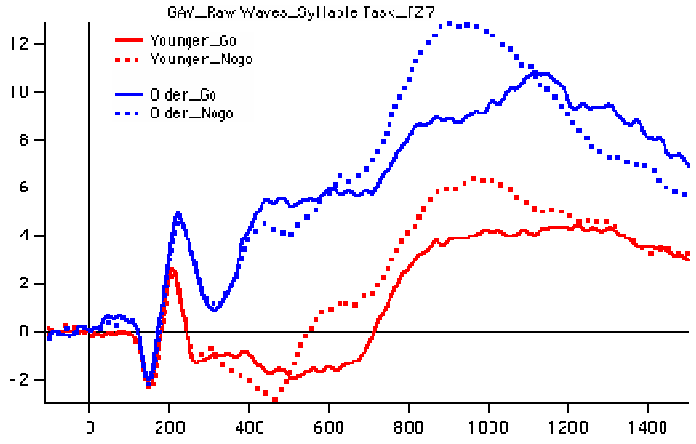
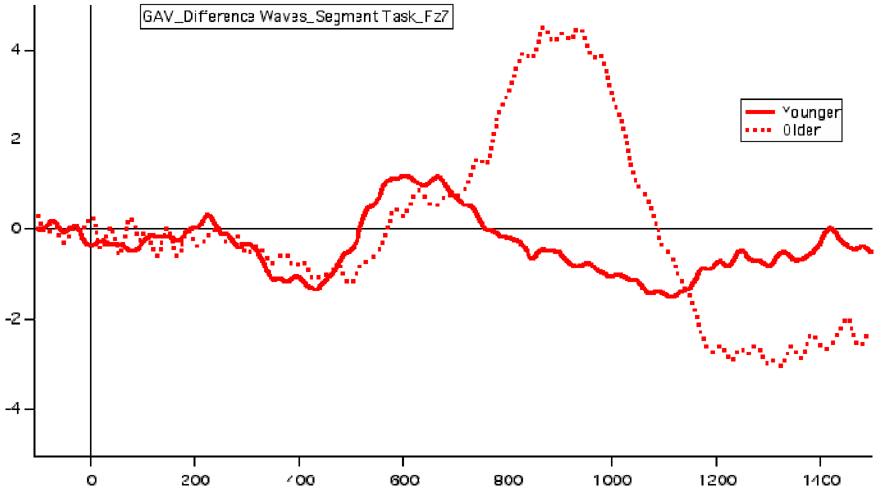


Figure 15

Group comparison of GAV N2d and P3d waves at site Fz7 on the A) Segment and B) Syllable tasks. Results revealed that older, as compared to younger, participants had a later N2d peak (negative peak between 251-600 ms) on both phonological tasks, and a greater P3d peak (positive peak between 601-1100 ms) on the segment task only. Note also the two-peak P3d effect in the younger group on the syllable task.

x-axis=time (ms); y-axis=amplitude (µV)

A) Segment Task:



B) Syllable Task:

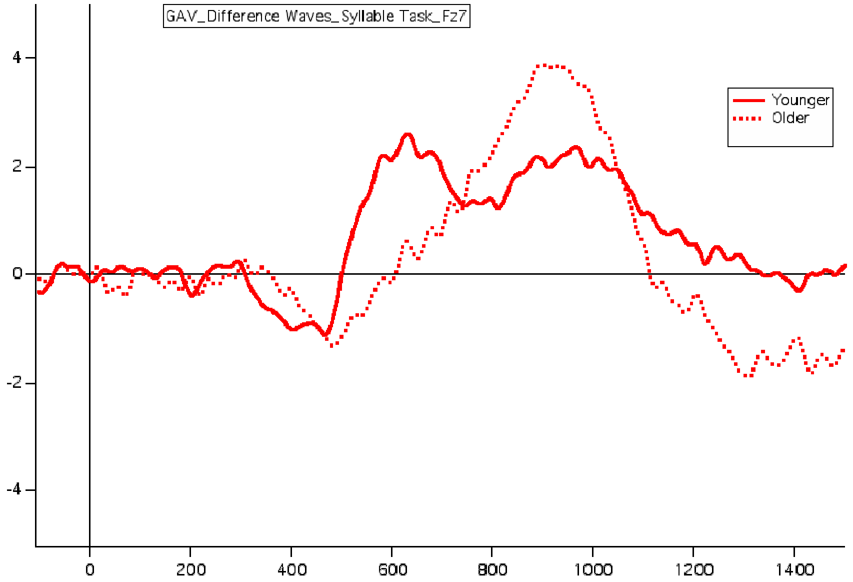


Figure 16

N2d Group x Stimulus x Time ANOVA revealed a Time x Group interaction

N2d Peak Group Comparison: Earlier (401-450 ms) for the younger than the older (451-500 ms) group.

Note: Vertical bars denote +/- standard errors

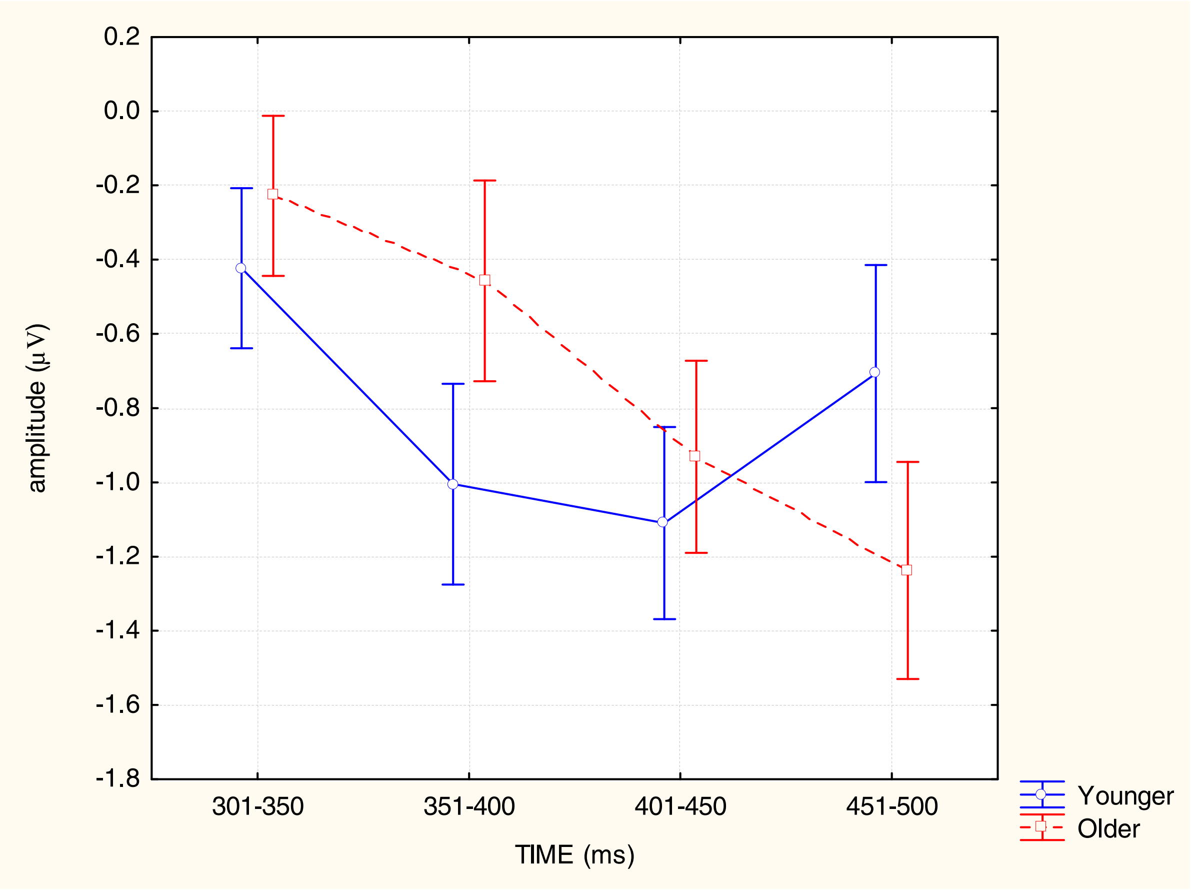


Figure 17

N2d Group x Stimulus x Time ANOVA revealed a Stimulus x Time interaction

N2d Task Comparison: The segment task had a significantly more negative N2d than the syllable task at time 301-350 ms, indicating earlier onset (below baseline) for the segment, than syllable, task.

Note: Vertical bars denote +/- standard errors

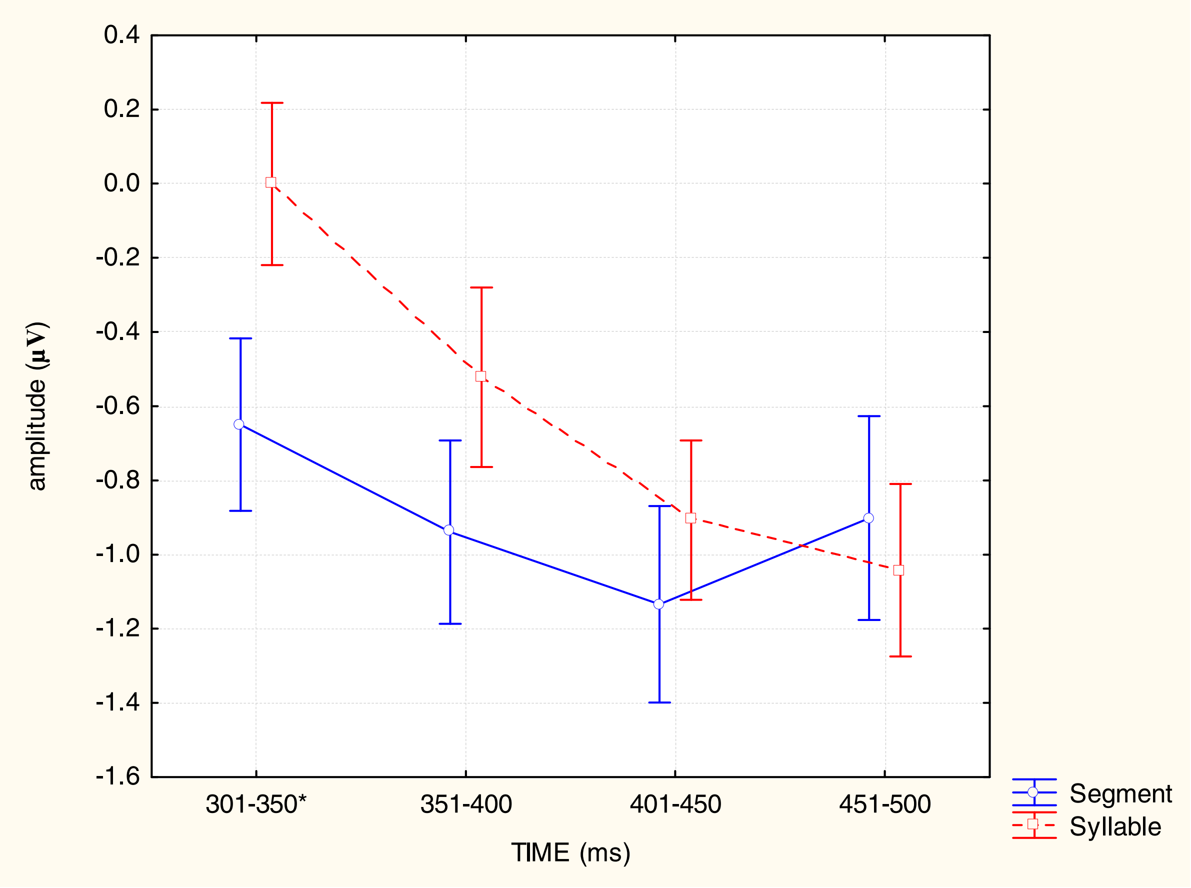
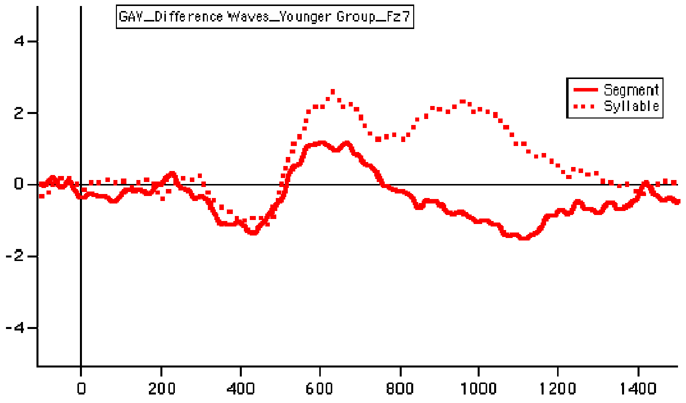


Figure 18

Task comparison of GAV N2d and P3d waves at site Fz7 in the A) Younger and B) Older group. Results revealed an earlier N2d onset (negative peak between 251-600 ms; point where the wave deflects below baseline) of 50 ms for the segment, as compared to the syllable, task in both groups, however, this task difference was only significant in the older group. Additionally, there were no significant P3d (positive peak between 601-1100 ms) latency differences between tasks in both groups

x-axis=time (ms); y-axis=amplitude (µV)

A) Younger Group:



B) Older Group:

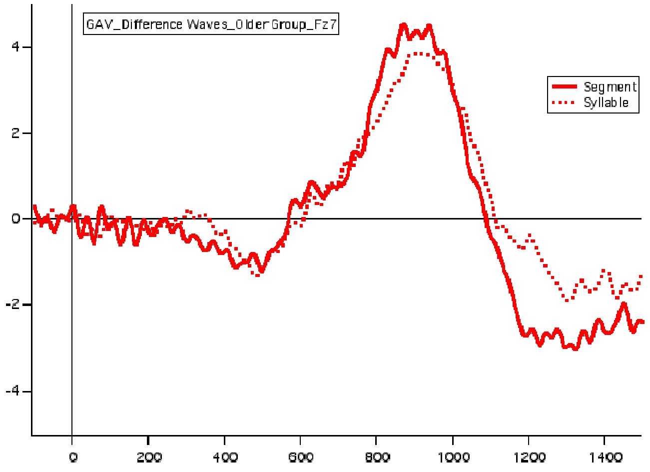


Figure 19A.

Topographical Map of P3d at Frontocentral Sites in Younger Participants on the Segment task. Time frames increase in 20 ms increments from 605-745 ms. The P3d appears largest (red at frontocentral and blue at posterior sites) from 605-685 ms. Scale: approximately 0.20 µV/step.

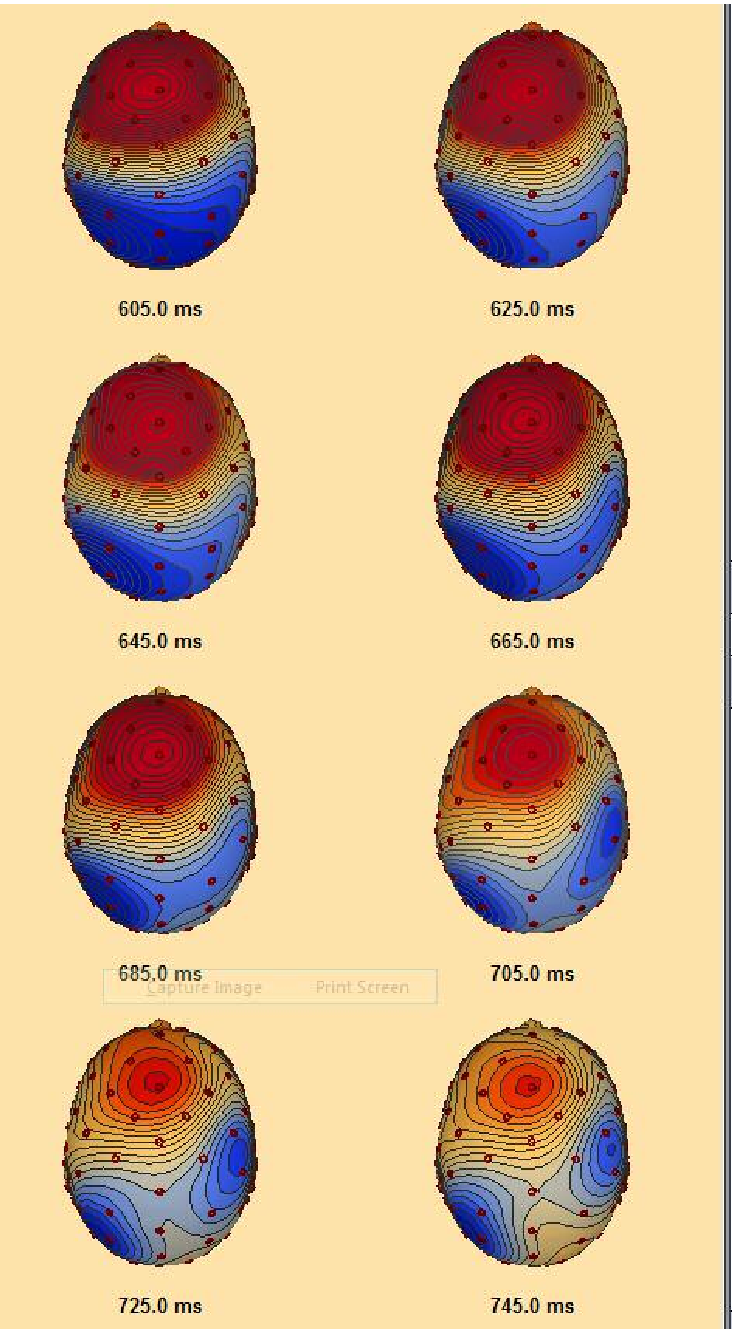


Figure 19B.

Topographical Map of P3d at Frontocentral Sites in Younger Participants on the Syllable task. Time frames increase in 20 ms increments from 600-1000 ms. The P3d appears largest (red at frontocentral and blue at posterior sites) from 601-750 ms and from 901-1000 ms. Scale: approximately 0.20 µV/step.

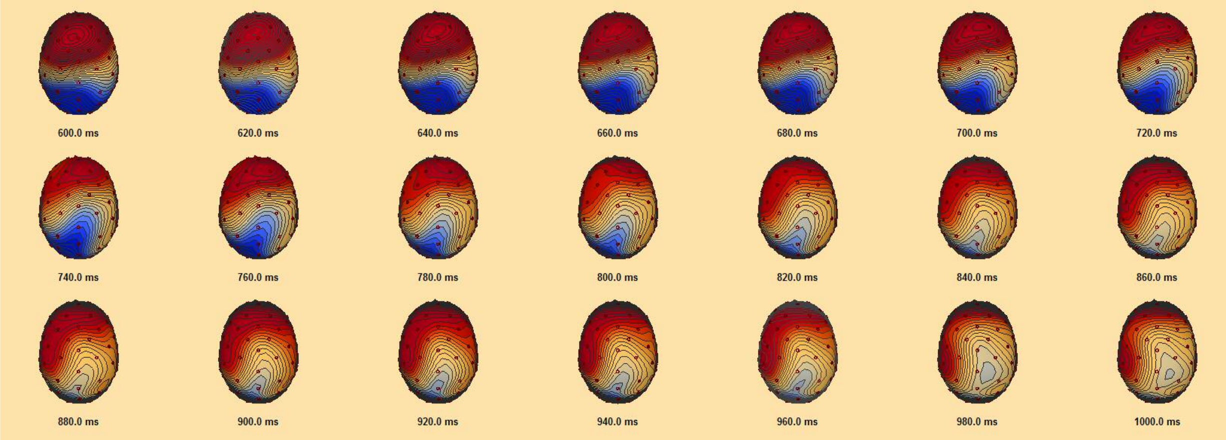


Figure 19C.

Topographical Map of P3d at Frontocentral Sites in Older Participants on the Segment task. Time frames increase in 20 ms increments from 615-955 ms. The P3d appears largest (red at frontocentral and blue at posterior sites) from 815-955 ms. Scale: approximately 0.20 µV/step.

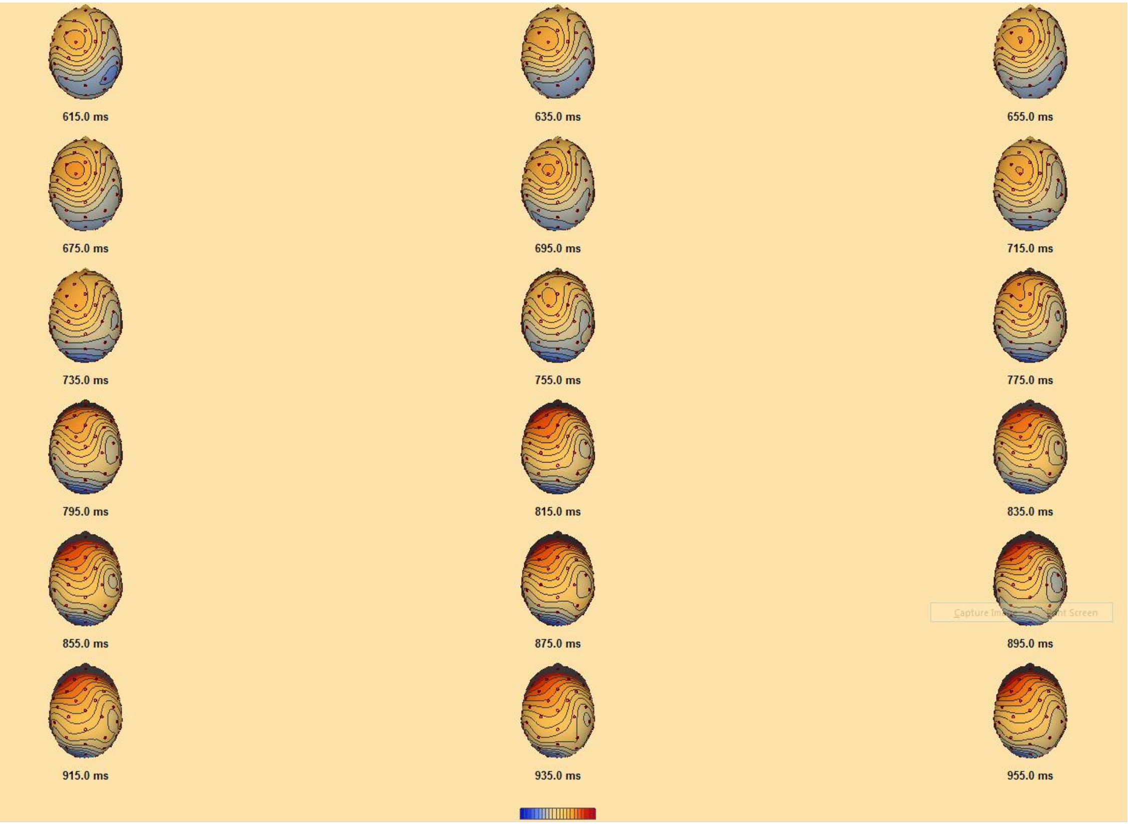


Figure 19D.

Topographical Map of P3d at Frontocentral Sites in Older Participants on the Syllable task. Time frames increase in 20 ms increments from 604-824 ms. The P3d is significant (red at frontocentral and blue at posterior sites) throughout the entire time range. Scale: approximately 0.20 µV/step.

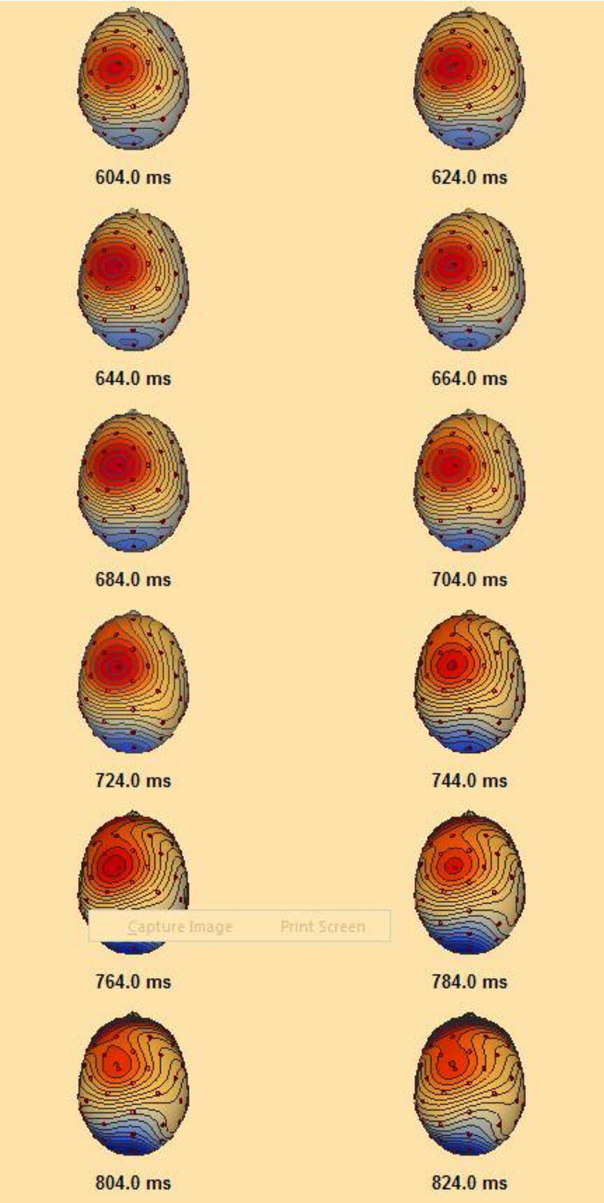


Figure 20

Significant P3d effect at times 601-750 ms in the Younger group on the Segment task

Note: vertical bars denote +/- standard errors

Response x Time interaction:

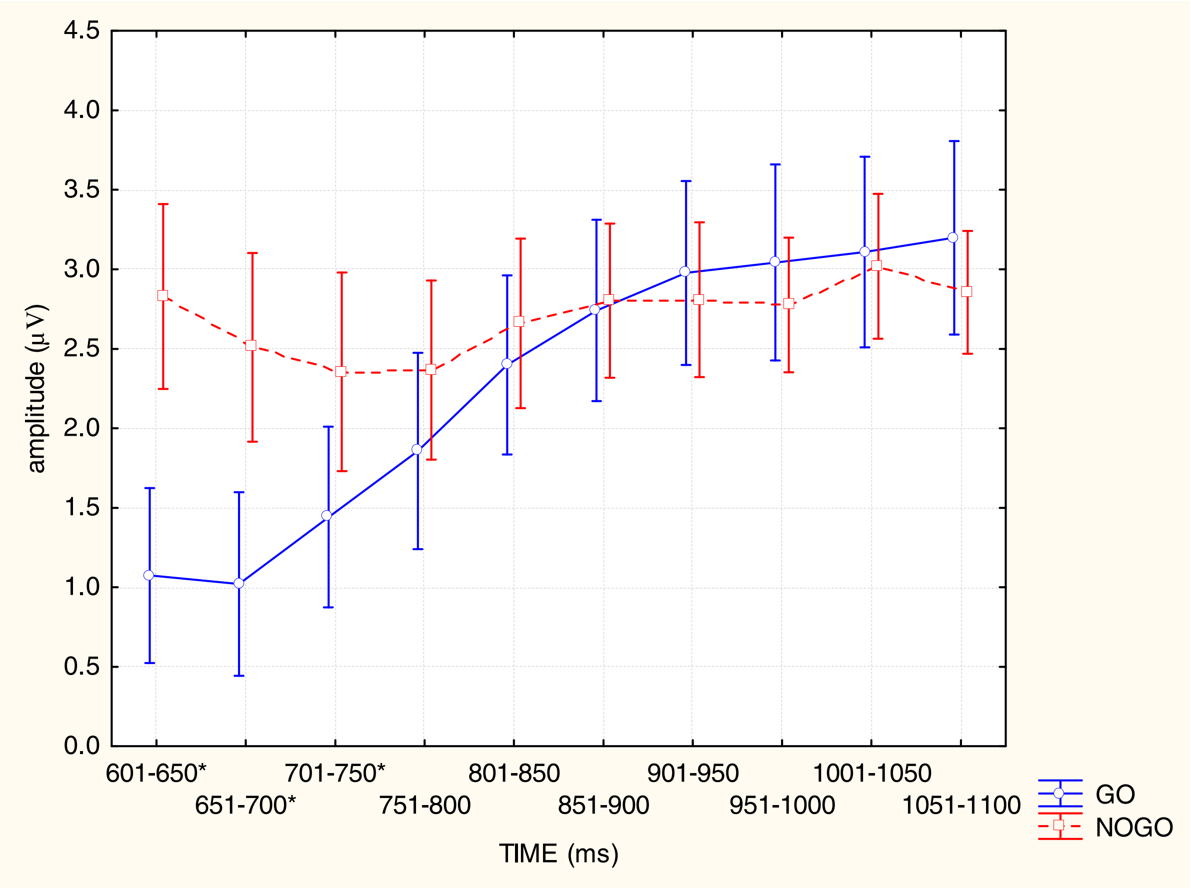
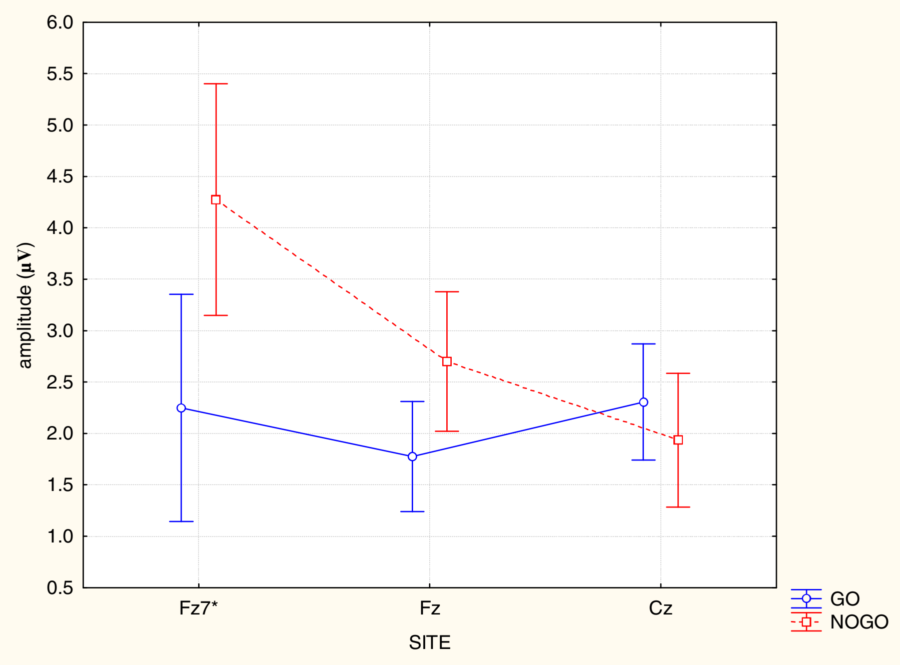


Figure 21

Significant P3d effect at site Fz7 and at times 601-700 ms in the Younger group on the Syllable task (Note: vertical bars denote +/- standard errors.)

Response x Site interaction:



Response x Time interaction:

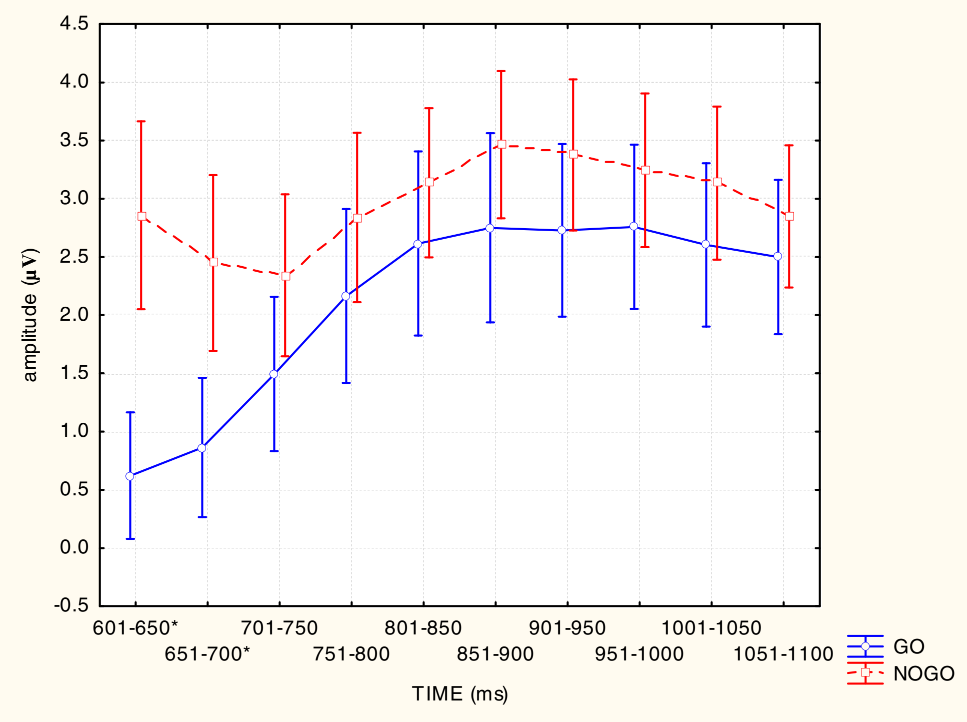
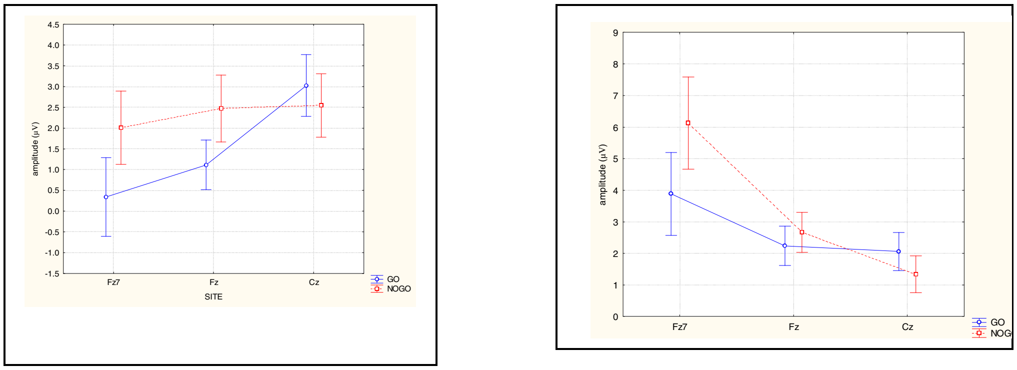


Figure 22

P3d Statistical Analysis: In the Younger group on the Syllable task, a significant Response x Site interaction was found at times A) 701-750, B) 901-950, and C) 951-1000 ms. Post-hoc testing did not reveal a particular site where the P3d response was significant. Observation of the graphs reveals the P3d effect (Nogo trials more positive than Go trials) was maintained at site Fz7 at all times, and at site Fz at time 701-750 ms and 901-950 ms. (Note: vertical bars denote +/- standard errors.)



A) 701-750 ms:

B) 901-950 ms:

C) 951-1000 ms:

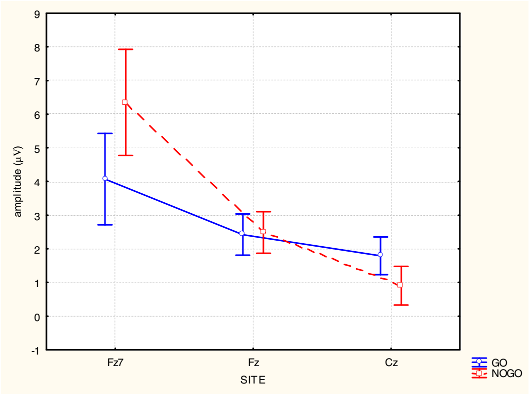
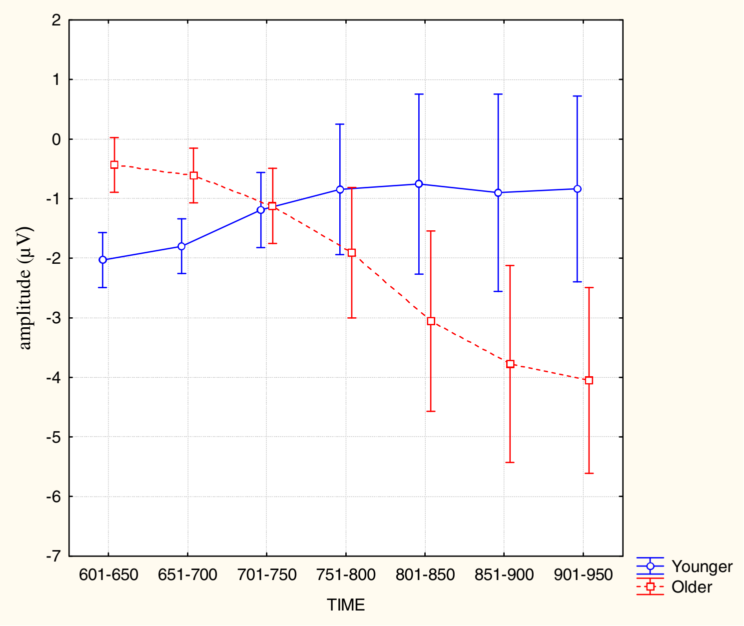


Figure 23

Time X Group interaction on A) both phonological tasks and B) the segment task only

Post-hoc testing: no significant P3d at each time interval. However, t-test results using contrast analysis for times 701-950 ms on the segment task reveal a significant group difference at times 851-950 ms. (Note: vertical bars denote +/- standard errors.)

A) Between group difference on both phonological tasks:



B) Between group difference on the segment task only:

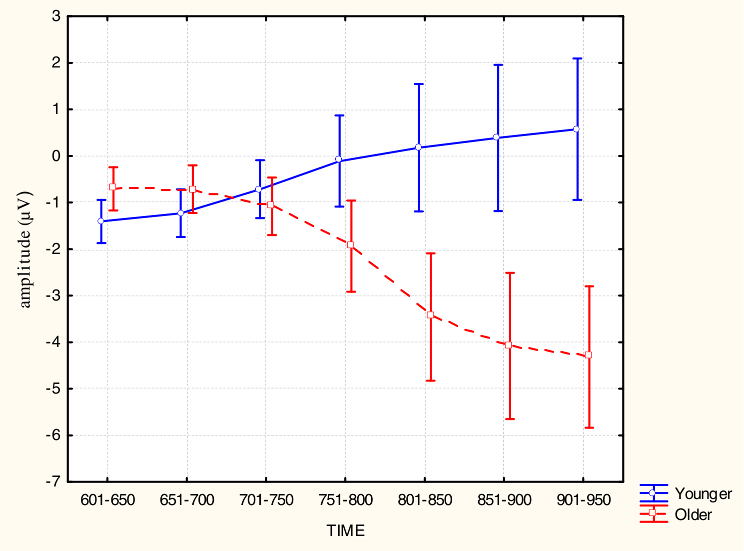


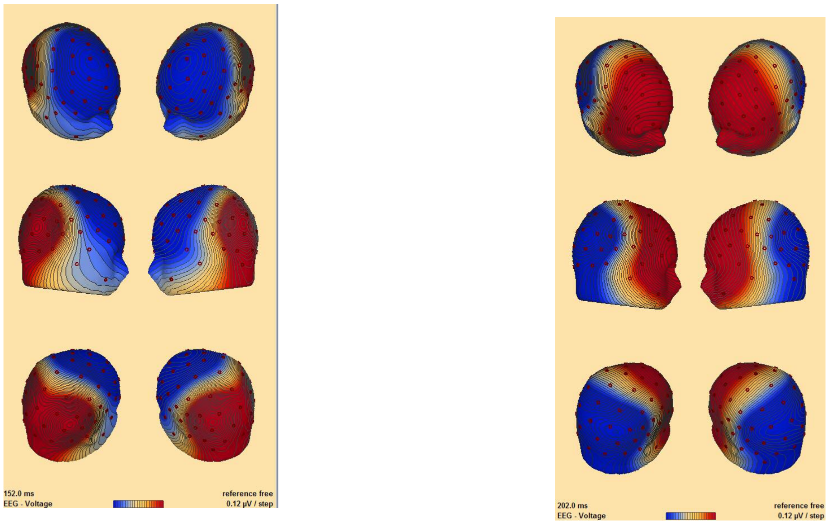
Figure 24

Topographical Map of VEPs of A) Younger and B) Older Participants on Go trials on the Segment task

Displaying posterior positivity at 150 ms that inverts over the frontocentral sites, and posterior negativity at 200 ms, inverting over the frontal pole.

Blue=Negative, Red=Positive

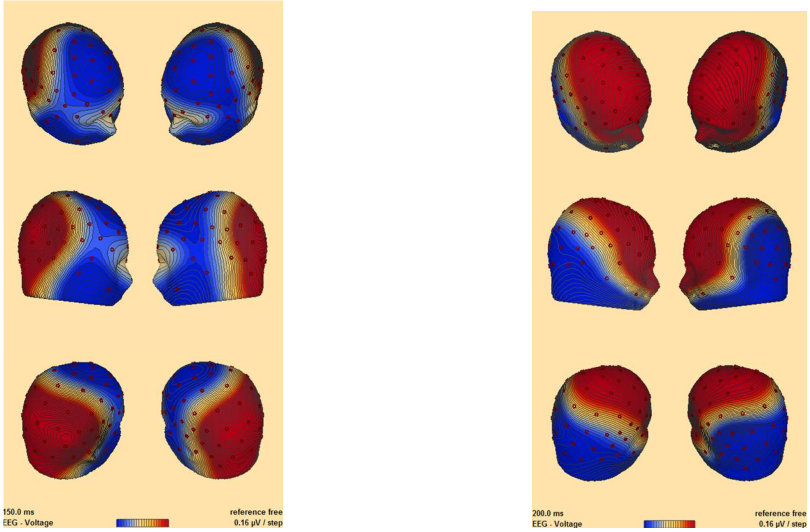
A) Younger Group:



Time: 150 ms

200 ms:

B) Older Group:



Time: 150 ms

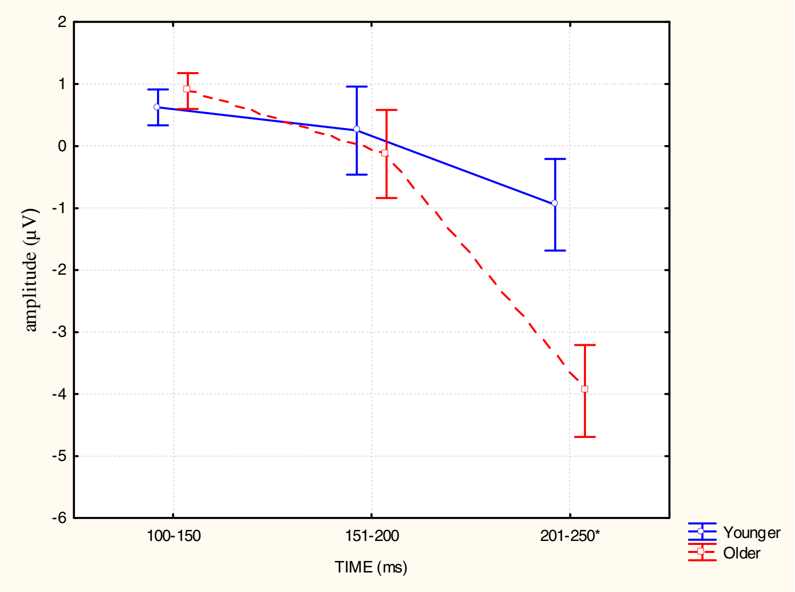
200 ms:

Figure 25

VEP Statistical Analysis at Site Oz: Time x Group interaction for both A) Go and B) Nogo response trials

Post-hoc testing revealed a significant group difference only for the Go trials at times 201-250 ms. (Note: vertical bars denote +/- standard errors.)

A) Go response trials:



B) Nogo response trials:

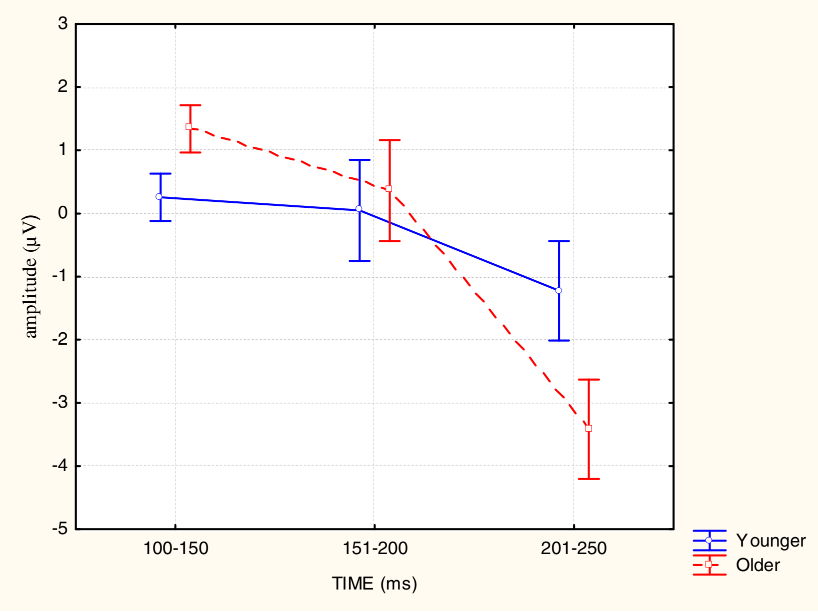


Figure 26

Plot of N2d Peak amplitude of Younger and Older Participants on the Segment Task

Results show that there was great variability in peak N2d amplitude at times 301-550 ms. Approximately nine older participants (E70, 74, 75, 76, 82, 83, 84, 87) and nine younger participants (Y42, 45, 46, 48, 50, 51, 96, 98, 99) showed data with two or more time intervals with amplitudes less negative than -0.5 μV.

x-axis=five time intervals (t1=301-350 ms, t2=351-400 ms, t3=401-450 ms, t4=451-500 ms, t5=501-550 ms); y-axis=amplitude (μV).

boxed-icons = younger participants; smooth lines = older participants

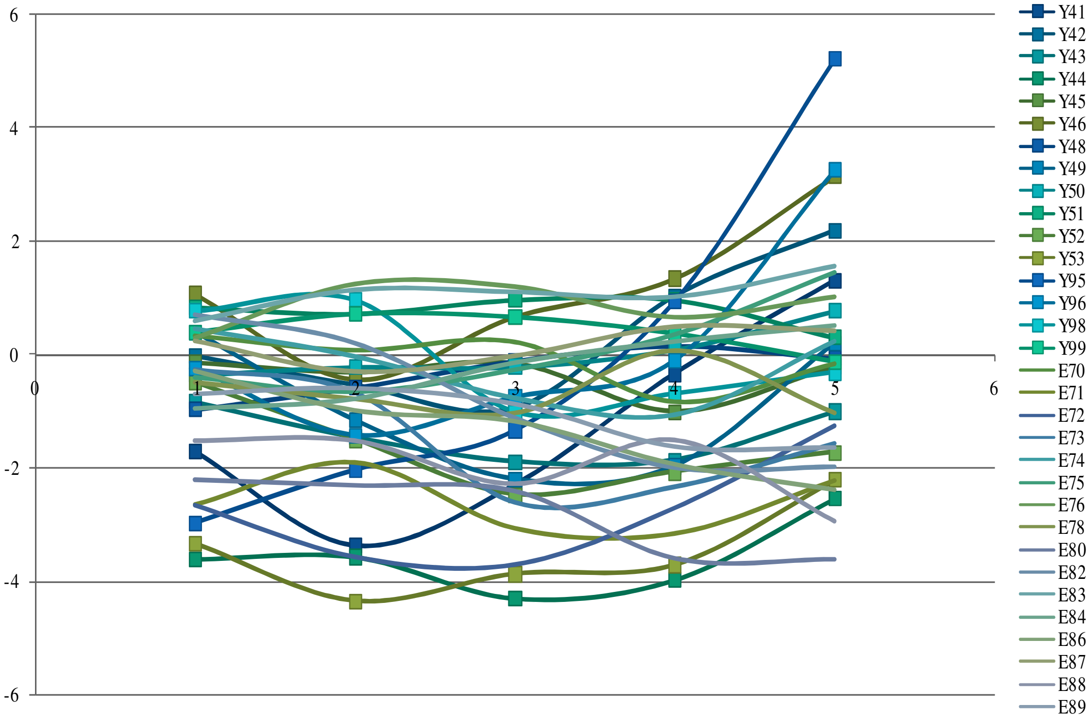


Figure 27A

Plot of N2d Peak amplitude of Younger Participants on the Syllable Task

Results show that there was great variability in peak N2d amplitude at times 301-550 ms. Approximately ten younger participants (Y42, 43, 45, 51, 52, 53, 95, 96, 98, 99) showed data with two or more time intervals with amplitudes less negative than -0.5 µV. x-axis=five time intervals (1=301-350 ms, 2=351-400 ms, 3=401-450 ms, 4=451-500 ms, 5=501-550 ms); y-axis=amplitude (µV).

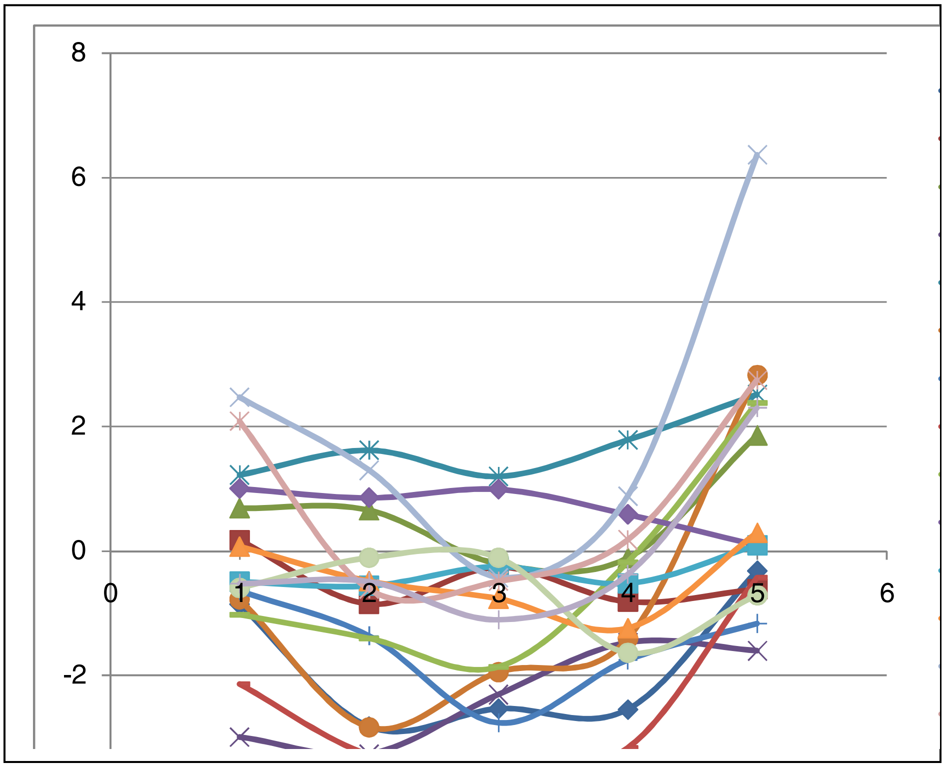


Figure 27B

Plot of N2d Peak amplitude of Older Participants on the Syllable Task

Results show that there was great variability in peak N2d amplitude at times 301-550 ms. Approximately nine older participants (E71, 76, 78, 80, 82, 83, 86, 87, 88) showed data with two or more time intervals with amplitudes less negative than -0.5 µV.

x-axis=five time intervals (t1=301-350 ms, t2=351-400 ms, t3=401-450 ms, t4=451-500 ms, t5=501-550 ms); y-axis=amplitude (µV).

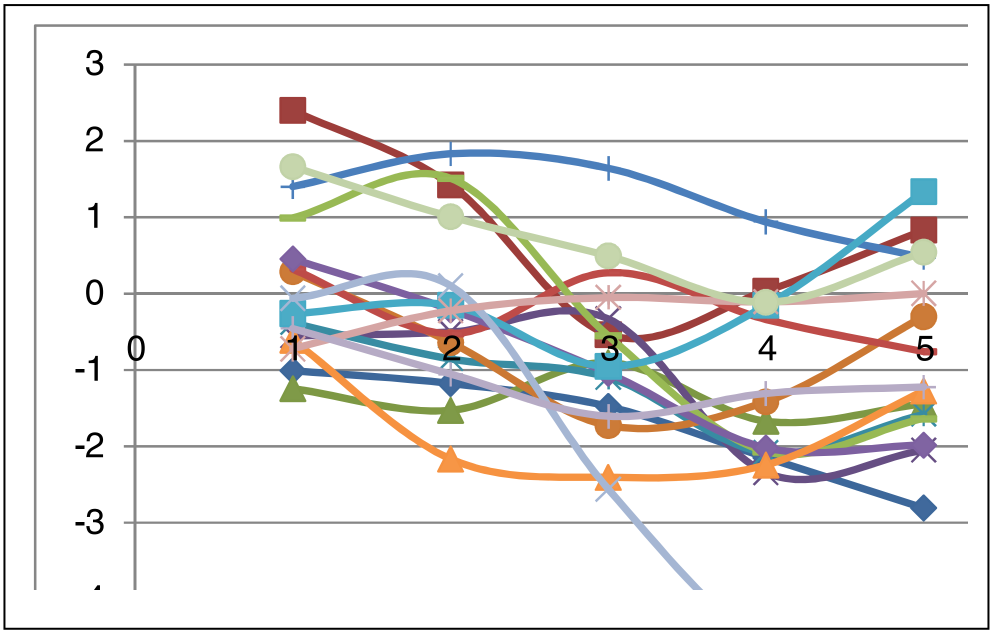


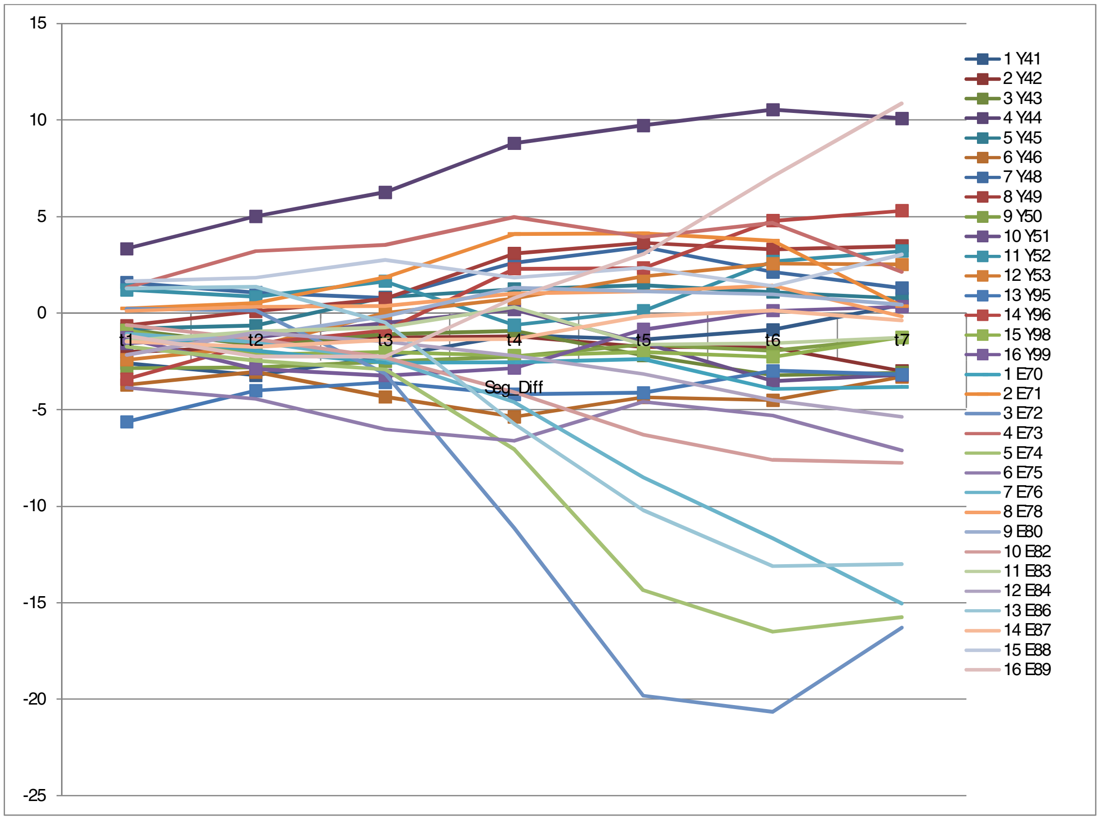
Figure 28

Plot of P3d Peak amplitude of Younger and Older Participants on the Segment Task

Results show that there was great variability in peak P3d amplitude at times 751-950 ms. Approximately seven older participants (E72, 74, 75, 76, 82, 86, 89) and one younger participant (Y44) presented with much variability (data with two or more time intervals with outlier amplitude data more positive than 5 μV or more negative than -5 μV from 751-950 ms).

x-axis=seven time intervals (t1=601-650 ms, t2=651-700 ms, t3=701-750 ms, t4=751-800 ms, t5=801-850 ms, t6=851-900 ms, t7=901-950 ms); y-axis=amplitude (μV).

boxed-icons = younger participants; smooth lines = older participants



Appendix A
Participant Background Questionnaire

Date: ______________
Case #:______________
Gender: M F
Age: _________
DOB: _________
Birthplace: _________________
Education (# of yrs): _________
Grade completed: ___________
At what **age**? ______________

Occupational History: ____
Language History:
Native Speaker of American English: ___________________________
Other Languages: ____
(What languages were spoken at your home when you grew up? What languages are spoken at your home now? Do you speak another language at home or at work these days?)
How well do you know these other language(s)?
1=Poorly 2=Somewhat 3=Good 4=Native-like
Lived most of life in NE part of US? ___________________________________
If not, where else have you lived? _____________________________________
For how long and when? ____
(Have you ever lived abroad for 4 months or more?)
Handedness (Self-report): **Right** Left Ambidextrous
(Use of hand for what you do most things with, not just writing)
Family sinistrality in first degree relatives (biological parents, siblings, children)
____
Neurological History:
Operation Information: Have you been hospitalized before?________________________
____
Have you been seen at any other time of your life by any other specialist? ____________
Psychiatrist/psychologist neurologist SLP special education teacher
(Did you ever have a stroke? Head injury?)
(Did you have difficulty learning to speak? Learning to read?)
Medications: ____
Tremors?______
Vision: WNL Corrected Vision: Glasses
Hearing Status: WNL Hearing Aid: Unilateral or Bilateral
TOT: Do you find that you have frequent TOT states? Y or N
Interest to participate in future research? _________________________________
Can I **contact** you if I have any further questions? _________________________

Name: ____
Address: ____
Tele #: ____

Appendix B

Informed Consent Form

INFORMED CONSENT

The purpose of this information is to help you decide whether you want to volunteer for a research study. Read carefully and ask the investigator about anything you don't understand.

Title of the Study: The Brain Basis for Word Finding Problems in Healthy Young and Older Adults_

Principle Investigator: Yael Neumann, M.S., CCC/SLP___________________________

Study Location: City University of New York, Graduate Center, Room 7392

General Information

- The purpose of this study is to understand how the brains of younger and older adults retrieve different types of information related to picture names.
- The time you will spend in the study will be approximately 1½-2 hours.
- The time you will spend in answering background and language-related questions will be approximately 10-15 minutes.

Experimental Procedure

- You will sit in a quiet booth and look at pictures.
- You will be asked to press buttons in response to different information.
- While you look at the pictures, your brain responses will be recorded from 65 tiny electrodes.
- The electrodes are wrapped in sponge and will rest gently on your scalp.
- The electrodes are soaked in a mild salt-water solution.
- It takes about 10-20 minutes to apply the electrodes to your head.
- This procedure is safe, and there is no known risk of personal injury.
- If you feel uncomfortable, you are free to stop at any time.

Benefits of Volunteering

- Your participation may contribute to a better understanding of the processes being studied.

Risk of Volunteering

- You may be uncomfortable with electrodes applied to your head.
- Inform the researcher if you are uncomfortable, or want to stop participating.

(continued on the back)

Appendix B (cont.)

Confidentiality of Your Records

- Your records will be kept in a locked file cabinet stored in the Graduate Center, CUNY's Developmental Neurolinguistics Lab, Room 7392.
- Authorized research investigators of the United States Food and Drug Administration, and the Department of Health and Human Services, may inspect the records from this research study.
- The research staff involved with this study will also have access to your records.
- Results of this study may be published, but will not include information that can identify you.
- You may receive a copy of the published paper on request.

Volunteering

- You should only take part in this research if you want to, and for no other reason.
- YOU MAY STOP PARTICIPATING AT ANY TIME, FOR ANY REASON.
- You may be removed from this study at any time, without your consent.
- You will be compensated at the rate of $8/hour if you do not complete the testing.

Contact Information

- If you have questions about this research, contact **Yael Neumann, M.S., M.Phil., CCC/SLP at (212) 817-8841; e-mail: yneumann@gc.cuny.edu or** my advisor **Valerie Shafer, PhD at (212) 817-8803; e-mail: vshafer@gc.cuny.edu**
- To learn more about your rights as a research volunteer, contact **Kay Powell, IRB Administrator, Graduate Center, City University of New York at (212) 817-7525; e-mail: kpowell@gc.cuny.edu**

Consent—By signing this form you agree that:

- You have fully read this form, or someone has read it to you.
- You had the opportunity to ask questions about this research and have received satisfactory answers.
- You understand that you are being asked to participate in research.
- You understand the risks and benefits in the procedures described above.
- You will receive a signed copy of this form, which is yours to keep.

______________________	______________________	____________
Print Your Name	Sign Your Name	Date

Investigator Statement

- I have fully explained to the participant the nature of this research. To the best of my knowledge, the participant signing this consent form understands the nature, risks, and benefits of this study.

______________________	______________________	____________
Investigator Name	Investigator Signature	Date

Appendix C

List of Practice Stimuli

12 Practice Stimuli:

Practice Items:

10 N vs. R		**10 1 vs. 2 syllable**		**12 Total Items:**
door	r	door	1	door
lobster	r	moon	1	house
pepper	r	swan	1	lips
ruler	r	house	1	lobster
tiger	r	lips	1	mitten
moon	n	pepper	2	moon
swan	n	ruler	2	pepper
mitten	n	tiger	2	ruler
telephone	n	mitten	2	swan
television	n	lobster	2	telephone
				television
				tiger

Appendix D

List of Experimental Stimuli

28 Experimental Stimuli:

Total 28 Test Items:	**Kucera and Francis written frequency:**	**Number of phonemes:**	**Category:**
pen	18	3	
chain	50	4	
barn	29	3	
corn	34	3	food
crown	19	4	
gun	118	3	
train	82	4	
iron	43	3	
lion	17	4	animal
chicken	37	6	animal
lemon	18	5	food
onion	15	5	food
wagon	55	5	
button	10	4	
bear	57	2	animal
hair	148	2	body part
chair	66	3	
star	25	3	
ear	29	1	body part
pear	6	2	good
deer	13	2	animal
anchor	15	4	
cigar	10	4	
finger	40	5	body part
flower	23	4	
guitar	19	4	
pitcher	21	5	
ladder	19	4	
MEAN:	37	3.61	
Standard Deviation:	33.04	1.17	

Overall Categories:

Food
corn
lemon
onion
pear
Body Parts
hair
ear
finger
Animals
lion
chicken
bear
deer

Appendix E

List of Experimental Stimuli per Tasks

Segment Task:

14 final /n/	**Kucera and Francis written frequency**	**Number of phonemes**	**Number of syllables**	**14 Final /r/:**	**Kucera and Francis written frequency**	**Number of phonemes**	**Number of syllables**
Pen	18	3	1		bear	57	1
Chain	50	4	1		hair	148	1
Barn	29	3	1		chair	66	1
Corn	34	3	1		star	25	1
Crown	19	4	1		ear	29	1
Gun	118	3	1		pear	6	1
Train	82	4	1		deer	13	1
Iron	43	3	2		anchor	15	2
Lion	17	4	2		cigar	10	2
Chicken	37	6	2		finger	40	2
Lemon	18	5	2		flower	23	2
Onion	15	5	2		guitar	19	2
Wagon	55	5	2		pitcher	21	2
Button	10	4	2		ladder	19	2
MEAN	38.93	4			**MEAN**	35.07	
Standard Deviation	30.12	0.96	0.52		**Standard Deviation**	36.77	0.52

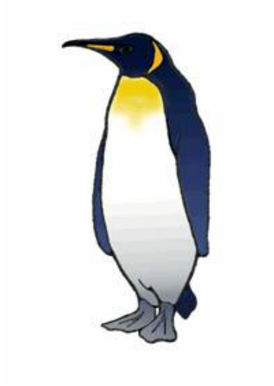
Syllable Task:

14 one-syllable (final /n/ and /r/)	**Kucera and Francis written frequency**	**Number of phonemes**	**Type of final phoneme**	**14 two-syllable (final /n/ and /r/)**	**Kucera and Francis written frequency**	**Number of phonemes**	**Type of final phoneme**
Pen	18	3	n	iron	43	3	n
Chain	50	4	n	lion	17	4	n
Barn	29	3	n	chicken	37	6	n
Corn	34	3	n	lemon	18	5	n
Crown	19	4	n	onion	15	5	n
Gun	118	3	n	wagon	55	5	n
Train	82	4	n	button	10	4	n
Bear	57	2	r	anchor	15	4	r
Hair	148	2	r	cigar	10	4	r
Chair	66	3	r	finger	40	5	r
Star	25	3	r	flower	23	4	r
Ear	29	1	r	guitar	19	4	r
Pear	6	2	r	pitcher	21	5	r
Deer	13	2	r	ladder	19	4	r
MEAN	49.57	2.79		**MEAN**	24.43	4.43	
Standard Deviation	18	3		**Standard Deviation**	13.71	0.76	

Appendix F

Diagram of Experiment Trial

+	.75 sec
Blank screen	.75 sec
Picture	1.5 sec



Blank screen	.75 sec

Appendix G

Summary of Experimental Timeline

1) Pre-familiarization of experimental and practice items with labels: 3 minutes

2) Practice testing of pictures without labels: 3 minutes

3) Administration of the Mini-Mental State Exam (MMSE): 5 minutes

4) Set-up of electrode cap: 20 minutes

5) Task 1: practice items: 3 minutes

6) Task 1: 280 experimental items (10 blocks of 28 items): 15 minutes

7) Re-calibrate equipment and re-measure impedances: 15 minutes

8) Task 2: practice items: 3 minutes

9) Task 2: 280 experimental items (10 blocks of 28 items): 15 minutes

Add approximately ½ hour for breaks, questions, snacks, etc., as needed.

<u>Total test time</u>: **approx. 97 min. = 1 ½ hrs.**

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