The Age-of-Acquisition Effect in Patients with Language Impairments

by

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Abstract

The age of acquisition (AoA) effect refers to the finding that words learned early in life are processed faster than words learned later in life. The influence of AoA has been found using many tasks, including picture naming, lexical decision, and eye-tracking methodology (Juhasz, 2005). Patients with language impairments such as aphasia, Alzheimer’s disease, dyslexia, dysgraphia, and those who have received an anterior temporal lobectomy are all influenced by AoA. The words that these patients successfully produce are often early-acquired, and when an error is committed, it is usually the result of a failure to retrieve a later-acquired word, suggesting that early-acquired words are better preserved in the mental lexicon than later-acquired words. The robust AoA effects found in these patient populations suggest that it could be an important tool for making more accurate diagnoses and constructing more effective treatment plans. The studies described in this review also shed light on a possible locus or loci of AoA in the mental lexicon. Through close examination of the performance of these patients on various tasks, it appears that AoA either resides in the semantic system, therefore supporting Steyvers and Tenenbaum (2005)’s “semantic hub” model or AoA could represent a general learning mechanism which is explained by Ellis and Lambon Ralph (2000)’s connectionist model and network plasticity.
Introduction

The ability to use language to communicate is a skill that readily develops shortly after birth in humans. Children utter their first word between the ages of ten to fifteen months and rapidly develop sophisticated language by the age of five (Siegler, Deloache, & Eisenberg, 2011). From this point on, children into adolescence and adulthood continue to add more and more words to their mental lexicon, which is the term used to describe the organization of the language processing system (Siegler et al., 2011). The three domains of the mental lexicon include orthography (word form), phonology (sound), and semantics (meaning). Retrieving a word from the mental lexicon (i.e. lexical access) is a somewhat taxing process involving recognition of the word form or picture, understanding, and production. A disruption anywhere along the line can result in failure to retrieve the correct word. Kittredge, Dell, Verkuilen, and Schwartz (2008) describe one model of lexical production consisting of two major steps: First, a holistic lexical representation corresponding to a specific concept is accessed and selection of the appropriate lexical unit occurs. Second, phonological characteristics of the word are accessed. It is thought that semantic errors, such as uttering “duck” instead of “swan” when looking at a picture of a swan, result from a disruption at the first step, whereas mispronunciations are the result of a disruption in the second step (Kittredge et al., 2008). Levelt, Roelofs, and Meyer (1999) cited by Kittredge et al. (2008) suggested a model in which speech production occurs in three steps, rather than two. Their model is similar to that of Kittredge et al.’s, but it includes a “lemma” access stage between the semantic representations and phonological representations. Selected for at the lemma level are grammatical aspects
of the word, such as gender, which is marked in certain languages such as Spanish and Italian (See Figure 1 for an adapted and simplified model of the mental lexicon). Various linguistic aspects of a word can affect word retrieval, making it either easier or more difficult to retrieve.

**Figure 1: Simplified diagram of the mental lexicon**

![Simplified diagram of the mental lexicon](image)

Note: This diagram was adapted from Kittredge et al. (2008) and Levelt et al. (1999)

Past research has demonstrated that words learned during early childhood are stored in or accessed from the mental lexicon differently than those learned later in childhood. More specifically, a substantial body of research (e.g. Carroll & White, 1973; Gerhand & Barry, 1998; Catling & Johnston, 2009) strongly suggests that words learned earlier in life are accessed more quickly or more accurately than words learned later in life. This phenomenon is called the **age-of-acquisition (AoA) effect**. The AoA effect has been demonstrated through the use of a wide variety of tasks such as word naming, picture naming, eye fixations, and lexical decision, to name a few (for a review see Juhasz, 2005). It can be measured in two ways: objectively, by
assessing the words children know at various ages by using an objective task such as picture naming, or subjectively, by asking adults when they believe they acquired a word. Most studies use subjective measures of AoA and many use norms gathered by Gilhooly and Logie (1980). For this norm database, participants were asked to rate when they thought they had learned a word on a 7 point scale, with 1 corresponding to the word being learned between ages 0-2 and 7 corresponding to ages 13 and above. Subjective ratings have been found to strongly correlate with objective measures of AoA (e.g. Gilhooly & Gilhooly, 1980), and are thus thought to be reliable measures of actual AoA.

**AoA and Other Lexical Variables**

Some researchers however, argue that AoA effects are actually cumulative word frequency effects and thus do not exert a distinct effect on word recognition and naming (e.g. Zevin & Seidenberg, 2002). Word frequency is a measure of how often a given word is encountered. Various measures of word frequency are used and are based on slightly different criteria. For example, the Kucera and Francis (1967) norms are based on how often a given word occurs in a sample of one million words. It has been demonstrated that words of higher frequency are processed faster than words of lower frequency (e.g. Oldfield & Wingfield, 1965). Thus, the argument that observed AoA effects are simply due to cumulative frequency can naturally be made since most words learned early in life will be encountered with a higher frequency than words learned later in life. Regardless, AoA effects are still found even when word frequency and cumulative word frequency are strictly controlled for (e.g. Hirsh & Ellis, 1994; Juhasz & Rayner, 2003). In addition to word frequency, AoA is also
highly correlated with many other psycholinguistic variables such as familiarity (the degree to which you come into contact or think about an object; Snodgrass & Vanderwart, 1980), imageability (ease of creating a mental image from the word), concreteness (the extent to which a word can be perceived by the senses), and word length (length in either letters or phonemes). It follows that early-acquired words are usually high in familiarity, imageability, and concreteness, and are generally short words. For example, the word “dog” satisfies all of these requirements. Thus, these variables must be taken into consideration when trying to isolate AoA effects.

**Theories of AoA**

The question remains as to where AoA exerts the strongest effects in the mental lexicon. Some believe that AoA can be localized to a single level of representation, whereas others support a more distributed influence of AoA, arguing that it affects all levels of representation, reflecting a general learning mechanism. Some researchers suggest that AoA affects the phonological system, such that words acquired earlier in life are stored as whole entities, whereas words learned later in life are stored as fragments, making them more difficult to retrieve (e.g. Morrison & Ellis, 2000). Support for this theory, however, is waning in light of new research (i.e. Monaghan & Ellis, 2002). Other researchers argue that AoA exerts an effect on the semantic system. Steyvers and Tenenbaum (2005) argued that early-acquired words occupy a more central place in the semantic network with more connections to other words, making them easily accessible. Later-acquired words thus have a more peripheral place in the network, with fewer connections to other words, making them
more difficult to access. This “semantic hub” model proposes that the speed and ease in which a word is accessed is due to its semantic richness within the network. It also hypothesizes that the rich interconnectivity of certain nodes could explain why early-acquired words tend to be preserved in the face of brain damage.

Another possibility, suggested by Ellis and Lambon Ralph (2000), is that AoA has an effect on network plasticity, and is therefore a general learning phenomenon. Using computer modeling to support a connectionist model theory, Ellis and Lambon Ralph demonstrated that when learning patterns are entered into the model early, the network becomes permanently structured in a certain way such that when later patterns are entered, learning becomes more difficult because of the crystallization of the network. This theory places the locus of AoA in the mappings or connections between different sets of representations, such as semantics and phonology. The strength of those mappings will depend on the point at which they were entered into the network. Ellis and Lambon Ralph (2000) also conducted a simulation in which they lesioned the trained network. They found that a damaged network could produce more correct responses to early-acquired items than later-acquired ones. As an addendum to the network plasticity hypothesis, Zevin and Seidenberg (2002) showed that when mapping from input to output is arbitrary (from orthography to phonology), a stronger AoA effect is observed. In other words, where there is an inconsistent spelling-to-sound correspondence, a greater AoA effect will be observed. Naming in English usually involves consistent mapping, or consistent spelling-to-sound correspondences, which Zevin and Seidenberg argue, gives way for cumulative frequency effects and not a true AoA effect. However, English also contains a
considerable number of words that are not easily mapped to phonology, such as “dough” and “tough,” as opposed to more consistent mapping with “dog,” “hog,” and “log,” for instance. Italian is a better example of a language with shallow orthography, meaning that the pronunciation of a word is highly predictable from its spelling. Therefore, studies conducted in many languages are essential for clarifying the mapping hypothesis. The arbitrary mapping hypothesis predicts that a greater AoA effect will be found when spelling-to-sound correspondences are inconsistent versus when they are consistent.

Another important hypothesis regarding the locus of AoA effects is the lexical-semantic competition hypothesis. Brysbaert and Ghyselink (2006) showed that AoA effect sizes were greater for picture naming than for word naming and lexical decision, calling this the frequency-independent AoA effect. They argue that this effect occurs when a unique concept must be selected, leading to increased competition in the conceptual system. This hypothesis argues for an AoA locus in the semantic system. This theory will be particularly important in this review because picture naming is the most widely used task to test language abilities of patient populations.

AoA has been shown to be a robust effect in word and picture naming tasks in healthy individuals. However, it is still debated as to where in the mental lexicon this variable exerts an effect. Additional data can be gathered from a collection of patient populations with deficits in language processing. In the past, studying patients has shed light on mechanisms of language processing. For example, in a study comparing deaf infants to hearing infants, it was shown that the lack of auditory feedback for the
deaf infants lead to disruptions in certain aspects of their vocalizations, demonstrating that auditory feedback is necessary for normal language learning (Schiener, Hammerschmidt, Jurgens, & Zeirner, 2006). Evidence for the locus of AoA can be gathered by examining how patients perform on various tasks that require them to access language and how it compares to that of healthy controls. This method allows one to study how various language skills deteriorate either due to illness, genetic disorders, or gradual age decline and how AoA relates to the specific language deficit observed. The possibility of AoA being used for diagnosis and treatment will also be explored. The populations that will be analyzed in this review include individuals with various types of aphasias, Alzheimer’s disease, dyslexia, dysgraphia (writing disorders), and lobotomy of the left anterior temporal lobe. A review on this topic was written in Italian in 2002 by Barca and Burani, but the current review will include dozens of additional studies conducted since the publication of the former review, and it will have an added emphasis on the clinical relevance of AoA in addition to the naming patterns found in patients. First, the various statistical methods used in studies examining patient populations will be discussed.
Statistical Methods

Since AoA is closely related to other psycholinguistic variables, it must be carefully controlled for either experimentally or statistically in order to determine which variable is exerts an effect on performance. For example, words that are early-acquired are also short, high in frequency and in familiarity, and concrete in meaning (Hirsh & Ellis, 1994). Thus, these tight intercorrelations must be unraveled in order to demonstrate the subtleties of each of their influences. The following sections will outline and discuss the common methods used to account for the intercorrelations between psycholinguistic variables.

Experimental Design Control

One type of experimental control is called a “semi-factorial design” (or partial factorial design) in which one variable is manipulated while the other is matched. For example, if AoA were manipulated, the stimuli included in the test would be either early-acquired or later-acquired and matched on other confounding variables such as frequency, familiarity, word length, and imageability. One limitation to using this design is that it is impossible to assess whether there are interactions between AoA and other variables, since only one variable is manipulated at a time. A factorial design (or orthogonal design) is another type of experimental control used in which two variables are crossed in order to detect any interaction between them. T-tests comparing the means are often used to analyze data gathered from a semi-factorial design, whereas an analysis of variance (ANOVA) is usually used to analyze data from factorial experiments. Cuetos, González-Nostri, and
Martinez (2005a) used both types of experimental control: they used a semi-factorial design to manipulate AoA and hold frequency constant and vice versa, and they used a factorial design to cross AoA and frequency in order to see if there was an interaction between them. Using semi- and full-factorial designs can be difficult because words that are matched on many variables except for one can be quite obscure. The multiple regression technique described below allows researchers to examine a large number of attributes in a single experiment and include more items in their test.

**Simultaneous Multiple Regression**

In the studies discussed here, the simultaneous multiple regression analysis is the most widely used. The first step in this method is to perform simple correlations between the psycholinguistic variables of interest. Simple raw correlations become difficult to interpret when there are many strong intercorrelations between variables. Thus, a multiple regression analysis is often employed, which allows for the evaluation of the independent contribution of any variable in predicting performance beyond those influences accounted for by the other variables, using success or failure on the given task as the dependent variable.

A **squared semi-partial correlation** is sometimes used in conjunction with a multiple regression analysis to remove the effect of one predictor from another predictor without removing that variability in the predicted variable. More specifically, multiple $R^2$ of all predictor variables is calculated and then the reduction in $R^2$ due to dropping each of the variables from the equation is determined. A
squared semi-partial correlation for a particular variable is considered to be
significant if dropping it from the regression equation significantly lowers the
proportion of variance explained (Hirsh & Ellis, 1994).

**Discriminant Analysis**

Discriminant analysis is used when analyzing individual data to predict
whether a particular item (with a certain combination of predictor variables associated
with it) will be successfully or unsuccessfully named. It assumes that multivariate
normality will be met and that the covariance matrices of all the groups are equal
(Ellis, Lum, & Lambon Ralph, 1996).

**Logistic regression**

Some prefer the use of logistic regression (e.g. Ellis et al., 1996) over
discriminant analysis when analyzing individual data because it is better suited to the
prediction of binary outcome (success versus failure), but does not make assumptions
about multivariate normality or equality in covariance matrices (Ellis et al., 1996). In
other words, the logistic regression analysis attempts to dampen the tendency for
relatively small changes in correct or incorrect items to cause dramatic changes in the
outcome of the regression analysis because it does assume a continuous dependent
variable (Weekes, Davies, & Parris, 2003).
Bootstrap Multiple Regression

Another type of multiple regression that has been used is called a “bootstrap multiple regression”. This method, employed by Gale, Irvine, Laws, & Ferrissey (2009), addresses the problem of healthy controls (even those who are age-matched) performing close to ceiling, while patients perform poorly, sometimes close to floor level. This presents a problem when the two groups are being compared statistically. This method is therefore used in circumstances in which there are many zero data points in the data set. To account for this problem, a relevant test statistic ($t$, $F$, $r$, etc.) is selected and then computed for $n$ permutations of the original group data, such that each data point returns to the sampling pool and can be redrawn multiple times afterwards. The result is a distribution of test statistics, rather than data points, which can be analyzed. This technique is an important tool to have when analyzing the non-normal distributions of data that result from comparing neurological impaired individuals with healthy controls.

Generalized Linear Mixed-Effects Modeling

Mixed-effect modeling, as carefully outlined by Baayen, Davidson, and Bates (2008), is basically an extension of multiple regression that takes into account variance due to sampling while simultaneously taking into account random variation between subjects and random variation between items. This technique is especially useful when using a repeated measures design (e.g. Rodríguez-Ferreiro, Davies, González-Nosti, Barbón, & Cuetos, 2009) since it helps to resolve correlations between responses for every participant and between participants for every item.
More specifically, models of the likelihood that a correct response or an error of a certain type would be elicited by a particular item in a participant’s naming are analyzed. Raw scores are used rather than aggregate scores, thus avoiding the loss of information.

When conducting a regression analysis, it is important consider the goodness of fit of the regression equation. The contributions of the independent variables found by regression analyses should only be taken into account if together all of the predictor variables constitute a significant percentage of the variation in performance. When studying the effects of psycholinguistic variables, there is not a single statistical technique that will be completely accurate. It is important to be aware of the different methods and to choose one that will best represent the data that has been gathered.
Non-Progressive Aphasia

Aphasia is the name for a category of language disorders resulting from brain damage due to stroke and sometimes other neurological disorders such as brain tumors and Alzheimer’s disease (Goodglass, 1993). The tendency to suffer from a stroke increases with age, along with the likelihood that one develops aphasia. There are many different types of aphasias, all with the common theme of impairing the patient’s ability to efficiently communicate through language. However, since the odds that two strokes affect the exact same regions of the brain is extremely low or zero, it is difficult to strictly define the different types of aphasia. In many cases there is overlap between the symptoms and deficits seen in patients, making it difficult to classify them as having a specific type of aphasia (Goodglass, 1993). One way to define the different types of aphasia is according to fluency. Broca’s aphasia, a type of non-fluent aphasia, is characterized by difficulty producing speech due to lesions encompassing Broca’s area in the brain (left frontal lobe; see Figure 2 for diagram of all aphasias). This difficulty seems to stem from motor output problems, as words are produced with labored articulation. Auditory comprehension is spared and patients often perform well on picture naming, but finding the correct vocabulary for free speech is often arduous (Goodglass, 1993). The opposite of Broca’s aphasia, Wernicke’s aphasia is characterized by fluent speech, but it is filled with poorly chosen words and sentences, which is sometimes referred to as “neologistic jargon” (Goodglass, 1993). Lesions to Wernicke’s area (the posterior portion of the first temporal gyrus) and the posterior region of the Sylvian fissure underlie Wernicke’s aphasia (Goodglass, 1993). Much like Wernicke’s aphasia, conduction aphasia is
fluent, but is characterized by disruptions in phonemes such as the transposition of the order of sounds and substituting or inserting extraneous phonemes. Conduction aphasia usually results from lesions to both the supramarginal gyrus region and along the border of the Sylvian fissure (Goodglass, 1993). Importantly, the difference between Wernicke’s and conduction aphasia is that comprehension is maintained in conduction aphasia, but is impaired in Wernicke’s aphasia (Goodglass, 1993). Areas of the brain involved in Wernicke’s aphasia are also involved in conduction aphasia, thus illustrating the fact that the different types of aphasia do not always remain distinct and that patients with conduction aphasia due to a lesion to the posterior Sylvian zone almost inevitably show symptoms of Wernicke’s aphasia as well (Goodglass, 1993).

Most of the studies done on aphasia in relation to AoA, have specifically sampled patients with anomia, a type of aphasia characterized by fluent speech and word finding errors (Ellis, 2006). This disability mostly affects nouns, but has also shown to disrupt retrieval of verbs, adverbs, and adjectives (Goodglass, 1993). These individuals have profound difficulty with picture naming tasks (i.e. Hirsch & Ellis, 1994). The underlying brain damage that leads to anomia cannot be pinpointed to a specific region – there are a plethora of areas including the angular gyrus region, areas of the frontal lobe, and the inferior temporal gyrus (Goodglass, 1993).
The following section will examine the characteristics of words (specifically AoA) produced by patients with various types of aphasia in picture naming tasks. Studies are conducted such that they either focus on patients as individual cases or they analyze patients as a group without distinguishing between the different types of aphasia. A plethora of past and current research will be combined and discussed in order to illustrate a clear picture of the AoA effects found in aphasic patients.

I. Influence of Age of Acquisition

Although aphasia has been closely examined for decades, with the first noted probable case in the Egyptian Edwin Smith Papyrus, dating back to 1600 BCE detailing speech problems after traumatic damage to the temporal lobe (McCrorry & Berkovic, 2001), only relatively recently has AoA been considered as a relevant
psycholinguistic variable to be studied. Rochford and Williams (1962) brought forth the possibility that the breakdown of linguistic processes could mirror the acquisition of these words and concepts in childhood. To investigate this idea, they tested 32 adult subjects suffering from speech disorders associated with organic cerebral pathology, dysphasia (now called aphasia), and 120 children between the ages of two and twelve years. A test of naming and comprehension was employed in which a card with six illustrations was presented to subjects who had to name the objects that were pointed to. Next, they were given names of objects and had to point to the correct corresponding picture. In the event of failure, they were given four cues until they gave the correct response. Test items could be arranged in a clear order of difficulty and a close parallel was found between the proportion of correct responses to each test item given by aphasic patients and the age at which correct responses were given by 80% of the children tested. Interestingly, in the analysis of errors, it was shown that errors made by patients were similar to those made by children. Overall, these results show that the names first learned in childhood are also the last ones lost by aphasic patients. In other words, Rochford and Williams (1962) showed an effect of AoA, although they describe it as an effect of word frequency, using the logic that words learned earlier in life are encountered more often over time than words learned later in life. They suggested two reasons for the findings in this study: The first being the frequency of rehearsal, referring to the fact that early-acquired words are practiced more over time than later-acquired words (i.e. the cumulative frequency hypothesis), and the second having to do with physiological stabilization of neuronal circuits over time. However, one could argue that stabilization of neuronal circuits
underlies long-term rehearsal. In a similar procedure to the one above, Rochford and Williams (1965) sought to further investigate the effects of word frequency on object naming. They found a significant correlation between word frequency (taken from the Thorndike-Lorge word count) and word finding difficulty, with lower frequency words being more difficult to recall. However, the experimenters failed to control for AoA, dismissing it as an influential variable separate and independent of word frequency.

Feyereisen, Van Der Borght, and Seron (1988) recognized the need to consider AoA as a variable with a real influence on word processing. In a replication of a study conducted by Howard Gardner in 1973, Feyereisen et al. sought to confirm the effects of operativity (a measure of the extent to which an object may be handled or used in daily life situations) found in Gardner’s study, but with stricter criteria to address methodological issues, and to examine the influence of related variables to operativity, such as familiarity and AoA. Eighteen French aphasics were presented with 64 line drawings taken from the Snodgrass and Vanderwart corpus (1980) one by one and asked to name the object in the drawing. Prior to presentation to the patients, words were rated by healthy subjects on operativity, familiarity, and AoA and frequency ratings were obtained from a French database. Through the analysis of errors produced, Feyereisen et al. (1988) found that operativity and frequency influenced naming performance. However, they also found that these variables were significantly correlated with familiarity and AoA. When AoA and familiarity were co-varied out, operativity no longer showed a significant effect and interestingly, the effect of frequency was not suppressed. A multiple regression analysis showed that
variance was most effectively predicted by AoA ($R^2 = 0.58$) and familiarity ($R^2 = 0.56$). The fact that frequency was not affected when AoA was partialed out, suggested that they exerted independent effects on aphasic naming, with AoA having the greatest effect. However, as Hirsh and Ellis (1994) pointed out, it is also possible that the performance of some of the patients studied by Feyereisen et al. (1988) may have been affected only by AoA and that of others only affected by word frequency. It is difficult to determine which scenario is most likely, since the patient data was combined into one group instead of analyzing individual cases.

In order to address the problem of the non-descriptive nature of data from large and undifferentiated groups of patients, Hirsh and Ellis (1994) presented data from a single case study of an individual with aphasia. Patient NP was given 100 items (pictures and words) and was assessed on spoken naming, written naming, reading aloud, and repetition. A multiple linear regression was conducted using AoA, imageability, concreteness, familiarity, length, and log frequency as independent variables. In addition, Hirsh and Ellis also used the squared semi-partial correlation procedure. This analysis showed that AoA explained the largest proportion of the variance in the spoken naming and written naming tasks. In a follow-up experiment done to more closely examine the effects of AoA, Hirsh and Ellis re-administered the 100 pictures from the first experiment, along with 64 additional pictures whose names have ratings for AoA, imageability, concreteness, and familiarity. The squared semi-partial correlation for AoA was again highly significant, especially for spoken naming, accounting for 7% of the variance. In their initial experiment, there was no significant relationship between AoA and reading aloud. Hirsh and Ellis re-
administered this task with two additional sets of 80 words, using a factorial design. In one of the sets, imageability levels were manipulated while frequency, length, and AoA were controlled, and in the other, AoA levels were manipulated while frequency, length, and imageability were controlled. This time, AoA was significant in both sets: NP read significantly more early-acquired words correctly than later-acquired words.

Interestingly, no effects of word frequency were found in any of Hirsh and Ellis’s (1994) experiments, which contrasts the findings of Feyereisen et al. (1988), who found frequency effects even when AoA was controlled for. However, it is important to note that Feyereisen et al. analyzed their data as a single group, rather than each individual case separately. Therefore, it is possible that some patients showed AoA effects and not frequency effects, some showed frequency effects and not AoA effects, and others may have shown effects from both. It is plausible that AoA and frequency make independent contributions to naming in aphasic patients and may influence distinct aspects of lexical processing, thus indicating different underlying pathological disruptions.

In analyzing the errors produced by NP, Hirsh and Ellis (1994) found that they were mostly semantic in nature and occurred during the spoken and written naming tasks. These were also the parts of the test that were significantly correlated with AoA. Therefore, by combining these two pieces of evidence, it seems plausible that AoA affects semantic representations of words, possibly by making these representations more readily available. However, Hirsh and Ellis suggested a phonological locus for AoA, arguing that AoA ratings refer to the age at which word-
forms, not concepts, are first acquired and that in order to conclude an influence at a semantic locus, one must relate AoA effects to the development of some part of the semantic lexicon, such as word-specific semantic representations.

In a multi-experiment study done by Nickels and Howard (1995), 12 aphasic patients (six fluent and six non-fluent) were given a picture naming task consisting of two sets of 104 line drawings of objects. AoA, operativity, frequency, familiarity, imageability, concreteness, word length in phonemes, and visual complexity were all analyzed as independent variables, but AoA, operativity, and word length were the only variables shown to significantly predict performance after a simultaneous multiple regression analysis was performed. Once again, the data was gathered from the patient group as a whole, and therefore does not illustrate the possible variations in performance between each individual, let alone the differences between the subgroups of fluent and non-fluent patients. In order to paint a clearer picture of the effects of lexical variables on picture naming, Nickels and Howard (1995) performed simultaneous multiple regressions on each patient individually. Five patients showed significant effects of AoA and seven showed significant effects of operativity. However, only two showed significant effects of both of these variables, decreasing the reliability of the group data which suggested that there were significant effects of AoA and operativity across the board. The finding that operativity exerts an effect on naming separate from AoA contrasts the findings of Feyereisen et al. (1988), who found that operativity effects disappeared once AoA was taken into account. However, they only analyzed group patterns, rather than individual performance patterns. Interestingly, in Nickels and Howard (1995)’s study, four out of the five
patients who showed an effect of AoA were classified as having fluent aphasia. This highlights the idea that there may be many subgroups within a patient population which show different characteristics when it comes to picture naming, but the authors failed to analyze this pattern further.

In a second study done by Nickels and Howard (1995), 15 aphasic patients (eight fluent, five non-fluent, and two apraxic; weakness or paralysis of speech muscles leading to laborious speech) were tested on a picture naming task consisting of 130 line drawings. The same variables were examined as in the first study except for visual complexity, which was excluded since it failed to reach significance in the previous study. Once again, using a simultaneous regression analysis, AoA and word length were found to have significant effects, but not operativity, contrary to the first study. Instead, imageability significantly predicted performance, along with AoA and word length. Individual data were analyzed by applying a discriminant analysis (since patients only attempted to name each object once), which showed significant effects of AoA for only three patients. Similar to the previous experiment, these three patients were classified as having fluent aphasia, suggesting that AoA is perhaps a better predictor of picture naming for individuals with fluent types of aphasia. Furthermore, when Nickels and Howard removed familiarity from the analysis, three more patients showed significant effects of AoA.

In order to investigate the locus of AoA, an error analysis was performed. There was no significant effect of AoA on the production of phonological errors, but a significant effect was found for semantic errors (also the finding of Hirsh & Ellis, 1994), suggesting a semantic locus for AoA. Nickels and Howard (1995) also argue
that there may be many loci at which AoA exerts an effect since there are a variety of factors which determine the age at which children acquire words.

Weary of the methodology of Nickels and Howard (1995), Ellis et al. (1996) replicated their study, but administered additional sets of pictures to the patients, instead of just one set, and then conducted individual analyses. Using a simultaneous multiple regression, they showed that AoA was the only significant predictor of group performance. In the individual analyses, logistic regression showed that AoA was only a significant predictor of accuracy for three out of six patients. However, these trends did not remain stable across two additional administrations of the picture sets. For example, Case 1 showed an AoA effect in the first and third administrations, but the effect was not significant in the second administration. Also, one of the patients in this study (Case 5, also known as NP from Hirsh & Ellis, 1994) showed no effects of AoA across all three administrations of the task, but in the study done by Hirsh and Ellis in 1994 (there was a four year gap between the studies), NP showed a strong effect of AoA. This highlights the fact that not only different statistical analysis produce different results, but that patients can also change over time. The strikingly different results gained from the use of different analyses suggests that statistical control (e.g. Ellis et al., 1996) should not always be used in place of experimental control (e.g. Hirsh & Ellis, 1994) and that both techniques should be considered when working with patient data.

Cuetos, Aguado, Izura, and Ellis (2002) followed the trend of analyzing both group data and individual data with simultaneous multiple regressions, but with an added focus on error analysis. Sixteen Spanish-speaking adult aphasics were given
140 line drawings to name. A simultaneous multiple regression analysis revealed that AoA, frequency, familiarity, and visual complexity all predicted performance accuracy of the group and the same analysis done on each individual demonstrated that AoA was by far the best predictor of accuracy. AoA was significant in 10 of the 16 cases and marginally significant in another two cases. Analysis of the errors made by the group showed that AoA was the only linguistic variable that predicted the proportion of semantic errors and phonological errors. However, when the data were broken down into individual cases, the picture did not remain as clear: AoA was shown to predict the performance of patients with mostly no-response errors, as well as those with mostly semantic errors, and even individuals with mostly phonological errors. Therefore, it is difficult to make definite conclusions about the predictive value of AoA for certain types of errors, since it seemed to predict all types of errors in this study.

Using a much larger group of aphasic patients (50), Kittredge et al. (2008) ran a series of experiments in which they investigated the relationship between AoA and frequency on error production in a picture naming task. They argued that analyzing errors is the best way to shed light on lexical access because certain error types can be associated with distinct steps of lexical access. Based off of a model outlined by Foygel and Dell (2000), Kittredge et al. carefully outline their preferred model of lexical access. This two step model (as mentioned in the Introduction) consists of L-level selection, in which a lexical unit is selected based on semantic input, followed by phonological selection. Prior to this process, there is also a conceptual domain in which semantic features are mapped to a concept. According to a computer
simulation based on the structure of this model, a variable must directly influence a particular lexical access step in order to have a significant effect on errors arising there. Thus, Kittredge et al. (2008) predicted that, for example, if AoA primarily affected phonological retrieval, then it should predict phonological errors. With regards to L-retrieval, AoA should predict semantic errors.

Semantic, phonological, and omission (also called no-response) errors were examined in this study, with a focus on frequency and AoA as independent variables. Using a multinomial logistic regression analysis, the authors found that both AoA and frequency predicted the likelihood of producing a correct response. Higher frequency of a word significantly decreased the odds of making a phonological, semantic, and omission errors. Early AoA showed a similar pattern, except that it did not significantly predict semantic errors, contrary to what has been found in the literature thus far (Nickels & Howard, 1995; Cuetos et al., 2002). The data suggested that frequency could have an effect at both steps of lexical access, L-retrieval and phonological selection, whereas AoA has an effect only at the level of phonological selection. It is difficult to interpret the meaning of omission errors as they can arise from either insufficient activation at the lexical level, failure of phonological retrieval, or even failure at the pre-lexical level during concept selection (Kittredge et al., 2008).

Error analysis in the literature thus far has been overwhelmingly contradictory. Although the aphasic population recruited by Kittredge et al. (2008) was much larger than past studies (i.e. Nickels & Howard, 1995; Cuetos et al., 2002), it is still possible that their sample did not include every small variation in deficits
found in aphasics. The conflicting data on effects of AoA on error production could also be evidence for a widely distributed effect of AoA: perhaps it exerts an influence at many or all levels of word retrieval.

_Pure Anomia_

Cuetos, Monsalve, and Perez (2005b) offered a possible solution to the confusion surrounding which part of the processing system is affected by AoA by studying patients with pure anomia. Individuals with pure anomia have difficulty specifically with lexical access (the connection between the semantic system and the lexical and phonological systems), with minimal or no damage to their semantic or phonological systems, meaning they know very well what they mean to say and they have no problem pronouncing words, but have difficulty in finding the right word for a picture naming task. Cuetos et al. (2005b) suggested that grouping patients based on which word production process is damaged is more effective than grouping them according to fluency. In order to determine which aphasics had pure anomia, they were given a word-picture matching task and a repetition task. A high score on both meant that they had a pure form of anomia.

Once the patients with pure anomia were identified, two studies were conducted by Cuetos et al. (2005b) in order to investigate the effects of AoA on picture naming. A semi-factorial design was employed in the first experiment in order to isolate the variables of frequency and AoA. An analysis of variance (ANOVA) showed that AoA was significant by subjects and items, whereas frequency did not reach significance. A factorial design was used in the second experiment in which
AoA and frequency were crossed to see if an interaction between them would emerge. Once again, the ANOVA showed that AoA was significant, whereas frequency was not. The authors were able to show clear effects of AoA on lexical access in the picture naming task. Furthermore, from this study, it can be concluded with relative confidence that AoA acts at the level of lexical access since this is the specific deficit seen in pure anomic aphasics. However, this does not rule out the possibility that AoA acts at more than one locus.

**Proper Name Anomia**

Proper name anomia, another subtype of anomia, is characterized by a deficit in retrieving proper names of people, places, and objects. Individuals with proper name anomia can often retrieve common nouns somewhat normally (Kay, Hanley, & Miles, 2001). Proper nouns are different from common nouns in many ways: they refer to a particular entity, but do not convey meaningful information about them, and it is possible that the links between semantic attributes and names are weaker for proper nouns than for common nouns (Kay et al., 2001). Two predictions about AoA effects can be made from this information: First, it is possible that since proper names have more arbitrary links to their referents than common nouns, AoA effects will be greater for proper nouns than common nouns, according to the arbitrary mapping hypothesis suggested by Zevin and Seidenberg (2002). Second, on the contrary, AoA effects may be larger for common nouns since they have more semantic connections than proper nouns. However, this second hypothesis is contingent on AoA having a semantic locus.
Kay et al. (2001) conducted a series of experiments to examine the effects of linguistic variables on name retrieval in a patient who had proper name anomia. In one experiment, two sets of line drawings from a variety of common noun categories were used to examine the effects of AoA and other linguistic variables on picture naming. The first set consisted of 100 drawings from Howard and Franklin (1988) and the second consisted of 195 drawings from Snodgrass and Vanderwart (1980). The patient, BG, was asked to name the pictures. A multiple regression showed that AoA predicted naming success for the first set, whereas AoA, familiarity, and name agreement (a measure of the number of correct alternative names that can be given to a picture) were all significant for the second set. It is clear that BG’s ability to retrieve the names of common nouns is strongly predicted by AoA. In the next experiment, the effect of AoA on BG’s ability to retrieve proper nouns was tested. She was asked to name 120 photographs of equal numbers of celebrities from the 1930s, 1940s, 1950s, 1960s, 1970s, and 1980s. She was given a cue for each name in order to increase the number of names she produced, which would give the authors more data with which to explore the effects of AoA. BG was significantly more successful in naming celebrities from earlier decades than from later ones, thus exhibiting an effect of AoA. However, the authors noted that they did not attempt to control for familiarity or frequency, which could have confounded the results. For example, celebrities who became famous earlier were probably more familiar and had a higher cumulative frequency.

This study does not compare AoA effect sizes between common noun retrieval and proper noun retrieval, but it would be an interesting area of future study.
However, this may prove to be difficult because of the fundamental differences between these two types of retrieval. As pointed out by Kay et al. (2001) retrieving proper names of people requires face recognition before the name can be retrieved from the lexicon. It is hypothesized that face processing and object processing follow different routes of retrieval in the brain, although this is still highly debated (i.e. Kanwisher, McDermott, & Chun, 1997; Gauthier, Skudlarski, Gore, & Anderson, 2000). On a similar note, Cuetos et al. (2002) highlighted the point that AoA could either affect word retrieval or object recognition, or possibly both.

**Neuroimaging**

Analyzing data from picture naming tasks and then drawing conclusions about what the data say about the organization of the mental lexicon is an extremely abstract process. One research strategy that can be used to give more concrete evidence for the mechanics of the word retrieval process is by using brain imaging, such as functional magnetic resonance imaging (fMRI). Postman-Caucheteux, Birn, Pursley, Butman, Solomon, Picchioni, McArdle, and Braun (2010) employed the use of event-related fMRI during a picture naming task. Three patients were also given a structural scan during the same session as the fMRI which revealed slightly different anatomical lesions for each patient, all within the left hemisphere. Interestingly, two of the patients classified as having anomic aphasia showed different lesions on the structural scan, providing further evidence that similarly diagnosed aphasic patients can show different underlying anatomical brain damage. This concrete data could also explain why different psycholinguistic variables predict naming performance in
different individuals, even when they are all classified as having the same disorder (e.g. Nickels & Howard, 1995; Ellis et al., 1996). Perhaps patients should be divided up onto subgroups based on their symptomatology and their specific structural lesions. On the picture naming task, the patients achieved 53% to 76% correct responses. The most common errors were semantic and omissions, which were predicted by a large number of alternative names and late AoA, respectively. The finding that AoA predicts omission errors is also supported by Kittredge et al. (2008).

Postman-Caucheteux et al. (2010) employed the use of neuroimaging to further investigate error production. They used BOLD contrasts comparing correct and incorrect responses and found that in both cases the left (language processing) hemisphere did not differ in activation level between conditions, whereas there was a significant difference in the right hemisphere. Incorrect responses were associated with increased activation of contralesional prefrontal areas, whereas correct responses did not evoke this activation. Furthermore, it was shown that AoA and the number of alternative names per target modulated the amount of brain activation in perilesional and frontal contralesional areas, in that later AoA and a high number of alternative names led to increased activation in these areas. Healthy, age-matched controls performed at ceiling on the picture naming task and exhibited exclusive left-hemisphere brain activation in the fMRI. It appears that the role of the right-hemisphere activation is compensatory, providing an alternative strategy for word retrieval. Blasi, Young, Tansy, Petersen, Snyder, and Corbetta (2002) proposed that the right frontal activation represents a visual or orthographic strategy, whereas the left frontal activation represents a linguistic or phonological strategy. Although the
right-hemisphere seems to offer an alternative strategy, the results of this experiment suggest that it is a less effective search and selection strategy. Increased right-hemisphere activation (in addition to normal left-hemisphere activation) was also associated with later AoA, which was associated with increased error production. It has also been shown that with second language activation after childhood, brain areas recruited during the use of this language are more widespread (including activation in the right hemisphere) than during the use of the first language (Neville & Bavelier, 1999). Therefore, it is possible that later-acquired words are distributed across the two brain hemispheres more than early-acquired words are, or that accessing later-acquired words requires additional assistance from the right hemisphere in a search and/or activation process.

II. Clinical Relevance

Given that AoA has been shown to predict picture naming success in multiple studies, it can be considered to be an important tool in therapy for aphasic patients. Laganaro, Di Pietro, and Schnider (2006) conducted a study on three anomic patients in which word retrieval was investigated during therapy. Replicating a robust finding in the literature, Laganaro et al. (2006) found that AoA was the only psycholinguistic variable that predicted baseline performance of all three patients on a picture naming task. For the therapy portion of the study, the patients were given a lexico-semantic written naming computer-assisted task consisting of 100 words that they had failed to name at baseline. An important aspect to this training program is that patients had the option of clicking a help-button which would provide them with the written word that
they could not retrieve. The program recorded the number of times each patient used the help-button. A simultaneous multiple regression was used to determine if any of the psycholinguistic variables predicted the number of help-button presses.

Phonological neighborhood (the set of words that differ from the target word by a single phoneme, such as sent and bent; Roodenrys, Hulme, Lethbridge, Hinton, & Nimmo, 2002) and image agreement were significant for one of the patients (PG), whereas AoA was significant for the other two patients (AH and TM), meaning that later-acquired words evoked more help-button presses. When these data were further examined, AoA was shown to be a significant predictor of help-button presses in TM, but was only significant for AH if the words retrieved without help were included in the analysis. The authors concluded that AoA predicted progress during therapy in TM, but that it affected naming accuracy in AH.

The results of this study shed light on two important points: the fact that phonological neighborhood was significant in predicting the number of help-button presses for PG, whereas AoA was significant for the other two patients, suggested that PG had a different underlying impairment even though all patients were classified as having anomia and their baseline picture naming performance was predicted by AoA. Another important point is that there seems to be a dissociation between phonological neighborhoods and AoA, as shown by patient PG whose progress was predicted by phonological neighborhood size, but not AoA. If AoA had a phonological locus, one would expect to see AoA effects alongside phonological neighborhoods. However, this was not the case with PG. Based on the significant effect of AoA on TM’s progress curve, the authors suggested a lexical retrieval locus
of AoA, hypothesizing that the AoA affects naming by either reinforcing lexico-
semantic connections or by lowering words’ activation thresholds. Once again, AoA
emerges as an important variable that not only predicts baseline performance, but also
the recovery process in some patients. Therefore, therapies for aphasic patients should
take into account AoA, first by screening them to see which patients’ performance are
significantly predicted by AoA, and then by training them on early-acquired words
first and gradually progressing to later-acquired words.

III. Conclusion

The data on aphasia can be somewhat confusing and contradictory. Overall,
AoA seems to have a strong and robust effect on picture naming accuracy. However,
the locus (or loci) at which AoA acts is slightly more difficult to disentangle. One
way used to investigate the seat of AoA in the mental lexicon was through error
analysis. Some found an AoA influence on semantic errors (Nickels & Howard,
1995), others found an influence on phonological errors (Cuetos et al., 2002), and
finally some found effects on omission errors (Kittredge et al., 2008). Postman-
Caucheteux et al. (2010) found AoA effects on both semantic and omission errors. It
is important to note, however, that Nickels and Howard (1995) did not include
omission errors in their analysis. Another method used was to look at a specific type
of anomia that is characterized solely by lexical access problems, called pure anomia.
Cuetos et al. (2005b) showed that AoA affected naming accuracy in pure anomia
patients, suggesting at least a lexical access locus of AoA. The least supported locus
seems to be at the phonological level, whereas the semantic and lexical access levels
remain highly plausible. Additionally, Laganaro et al. (2006) showed that AoA predicted baseline performance in some patients, but not all, and that this could be an indicator of a specific subtype of aphasia. They also provided promising data showing that AoA predicted improvement in naming performance in one patient, suggesting the possibility that training patients on early-acquired words and then progressing to later-acquired ones could be an effective treatment method. In the future, studies should employ the use of more diverse tasks, such as lexical decision and verbal fluency, in order to investigate the effects of AoA on aphasic patients.
Primary Progressive Aphasia

Primary Progressive Aphasia (PPA), also called semantic dementia, is a form of dementia defined by Mesulam (2001) as a progressive disorder of language, with preservation of other mental processes such as activities of daily living for at least two years. PPA is usually associated with progressive atrophy of the anterior temporal lobes, particularly of the inferior temporal gyrus (Lambon Ralph, Graham, Ellis, & Hodges, 1998). Importantly, PPA is defined as being different from Alzheimer’s disease, which severely impacts other aspects of mental functioning such as attention, memory, and visuospatial skills, in addition to language. However, in practice, it is often difficult to make a clear clinical distinction between the two diseases because PPA patients may display some deficits in mental functioning outside of language, but usually not to the same severity of Alzheimer’s patients. It is not uncommon that patients are initially diagnosed with PPA, and then later re-diagnosed as having Alzheimer’s disease as their condition worsens. Thus, some of the studies in this section may include patients with Alzheimer’s disease and PPA in the same analysis. Initially, patients with PPA experience difficulty in finding appropriate words (anomia) which then progresses to disturbances in grammatical structure and comprehension of language (Mesulam, 2001). Speech output of these individuals can either be fluent or non-fluent (Mesulam, 2001).

I. Influence of Age of Acquisition

As described above, PPA is a type of aphasia that is degenerative in nature, instead of vascular. Patients display word finding difficulties (anomia), but their disease worsens over time. Some of these patients are classified as having
Alzheimer’s disease, but the line separating the two diseases is not always clear, as discussed above. Although patients with PPA show the same symptoms as patients with “normal” aphasia, their disease is the result of a different underlying problem. Therefore, it is important to examine whether the linguistic performance of individuals with PPA will also be affected by the same psycholinguistic variables.

Hirsh and Funnell (1995) conducted a study on two patients with PPA: Mary and EP. Although both patients had fluent PPA and had anomic aphasia, Mary was clinically diagnosed as having dementia of the Alzheimer type, whereas EP was diagnosed with semantic dementia. Hirsh and Funnell (1995) administered both a picture naming and word-picture matching task to Mary and EP. A decline in naming comprehension over time was shown, providing further proof of the progressive degenerative nature of their disorder. Furthermore, Mary’s decent scores on the word-picture matching task shows that her comprehension was still mostly intact, whereas EP’s poor performance on the same task demonstrates that her pathology involved a lack of comprehension. Using a simultaneous multiple linear regression, the authors showed that Mary’s naming performance was significantly predicted by AoA, while EP’s performance was predicted by familiarity. Consistent with studies on non-progressive aphasia (i.e. Kittredge et al., 2008; Postman-Caucheteux et al., 2010), Mary, the patient whose performance is predicted by AoA, also exhibited mostly no-response or omission errors. EP displayed mostly semantic errors and a generous number of no-response errors as well. The authors offered the interpretation that familiarity exerts an influence at the semantic level (as shown by EP), whereas AoA affects lexical-phonological processing (as shown by Mary). It is important to note
that Mary’s omission errors cannot be confirmed as a lexical-phonological processing
deficit, since it is difficult to pinpoint the underlying deficit behind an omission.
However, the fact that Mary resolved many of her errors with phonemic cueing (the
authors provided the first phoneme if the patient failed to respond within 15 seconds)
suggests that AoA does indeed have a locus at the lexical-phonological level.
Furthermore, EP did not respond to phonemic cueing, suggesting that this part of her
mental lexicon was intact and that her deficit was of the semantic nature.

Lambon Ralph et al. (1998) criticized Hirsh and Funnel (1995)’s modular
approach to the mental lexicon and for coming to what they considered to be
premature conclusions. They argued that it cannot be simply concluded that AoA and
familiarity have a single locus in the mental lexicon. Rather, they offered a situation
in which speech production is a cascading process, such that AoA can exert an effect
on someone with a semantic impairment by facilitating the lexical-phonological
access process. In addition, impairment of the lexical-phonological system can be
influenced by familiarity, which would boost semantic activation of certain concepts
and influence the lexical-phonological system through cascading activation. Lambon
Ralph et al. (1998) simply offered an explanation that is interactive, rather than the
modular model proposed by Hirsh and Funnel (1995).

Lambon Ralph et al. (1998) conducted a study on a larger sample of patients
with PPA in order to further investigate the psycholinguistic effects found by Hirsh
and Funnel (1995). Nine patients were each asked to name 132 pictures from the
Snodgrass and Vanderwart (1980) database. A linear regression was used to analyze
the group data, which showed that AoA, object familiarity, and spoken frequency all
significantly predicted naming accuracy. The logistic regression used in the individual analysis revealed that the performance of each individual was, for the most part, affected by the same variables that the group as a whole was, contrary to the findings of most non-progressive aphasia studies. Interestingly, the results for each patient did not vary based on the severity of their anomia or laterality of atrophy. In contrast to findings of past studies on non-progressive aphasia and the PPA study done by Hirsh and Funnell (1995), it appears from these data that there is somewhat of an “average” profile of PPA, regardless of the slight differences in atrophy and severity of symptoms. Since PPA is a progressive degenerative disorder, it will be important to investigate whether AoA predicts performance over time.

Lambon Ralph et al. (1998) followed one of their patients, JL, for two years in a longitudinal study. His performance on the picture naming task was assessed four times, revealing that AoA and object familiarity predicted his accuracy for the first three administrations before he became extremely debilitated by the fourth, at which point none of the variables predicted his performance. In a combined analysis across the four sessions, spoken frequency also became a significant predictor.

Lambon Ralph et al. (1998)’s selection of patients all displayed semantic deficits and were almost all affected by AoA (7/9), which contrasts the finding that EP’s (also a patient with semantic deficits) performance was predicted only by familiarity, and not AoA in Hirsh and Funnel (1995)’s study. One possible reason for this could have been that the analysis did not have sufficient statistical power to resolve factors that were weaker than familiarity. Lambon Ralph et al. (1998) offered the possibility that their patients could have had an underlying lexical-phonological
deficit in addition to their semantic impairments, which is affected by AoA. Thus, they interpreted their data with the theoretical basis of a cascading model of language production instead of a modular one. According to this idea, AoA reflects the ease at which a lexical-phonological representation can be activated, which is especially helpful when there is very little cascading semantic activation because of impairment in the semantic system. Therefore, by lowering the threshold of activation at the lexical-phonological level, AoA can facilitate word retrieval even when there is limited activation from the semantic system. The effect of familiarity found in this study therefore affected semantic representations, while AoA affected lexical-phonological representations.

Another longitudinal study was done by Ukita, Abe, and Yamada (1999) on a Japanese-speaking patient with non-fluent PPA. Their goal was to test a weak version of the “regression hypothesis” which states that patients with PPA should lose later-acquired words before early-acquired words (Ukita et al., 1999). This regression is thought to exactly mirror the acquisition of words in childhood, similar to what was shown by Rochford and Williams (1962). The patient was tested four, five, six, and seven years after the onset of the aphasic symptoms on a picture naming task. Importantly, since the Japanese language is so different from English, they approached the variable, AoA, in different way. AoA ratings were obtained from a database of 86,855 words that three children produced from the age one to age five. AoA was divided into words that were early-acquired, later-acquired, and in-between words, rather than just the two traditional categories of early- and later-acquired words. Related to AoA in Japanese, the authors also took into account the variable
“historical word status” because Japanese words can either be original, Sino-Japanese, or loan words borrowed from either English or other European languages (Ukita et al., 1999). Importantly, original Japanese words tend to be acquired earlier than the other two types.

The patient showed a characteristic decline in picture naming accuracy across the four years of testing. Interestingly, he was able to revive some words in the later sessions that he originally could not retrieve in the first testing session. These revived words were associated with early AoA, more so than lost words. Although this study found an effect of AoA on naming, the authors failed to include other variables known to correlate with AoA such as familiarity. Instead, they only included frequency, AoA, and historical word status. Therefore, the results should only be tentatively accepted, until more variables are controlled for. The fact that revived words were early-acquired could be important to the development of cognitive therapies which teach patients to learn early-acquired words first, before moving on to more difficult later-acquired words.

Kremin, Perrier, De Wilde, Dordain, Le Bayon, Gatignol, Rabine, and Corbineau (2001) examined picture naming in eight patients with PPA, and using a multiple regression analysis, they found that AoA determined naming accuracy in five of the patients. Name agreement also predicted naming in five patients, along with visual complexity, category membership, and frequency to a much lesser degree. Once again, the robustness of AoA as a predictor of naming performance is clearly exemplified by this experiment.
Using a database with 225 sets of picture naming data from 78 patients with semantic dementia, Woollams, Cooper-Pye, Hodges, and Patterson (2008) set out to analyze the influence of various characteristics of target words or objects in the picture naming tasks on accuracy, as well as error production. A simultaneous multiple regression once again confirmed significant effects of AoA, familiarity, and frequency, as shown by Lambon Ralph et al. (1998). Interestingly, typicality emerged as the best predictor of naming accuracy. Woollams et al. (2008) found that the most common type of error was an omission, with semantic errors not far behind. This error pattern is concordant with the findings of Lambon Ralph et al. (1998). The fact that most of the errors were related to retrieval errors rather than completely incorrect answers such as circumlocutions gives evidence for semantic dementia being the result of degraded knowledge rather than a distorted semantic system (Woollams et al., 2008). Unfortunately, the authors only chose to analyze typicality in relation to error production (low typicality was associated with omissions, whereas high typicality was associated with semantic errors), and not AoA. A future study utilizing the same large database of patients and their performance on picture naming tasks in the analysis of AoA and error production would be beneficial for understanding the locus at which AoA acts.

II. Clinical Relevance

The study done by Ukita et al. (1999) showed that their non-fluent PPA patient was able to revive words over a period of four years, and that they were early-acquired. This phenomenon could be used to construct new cognitive therapies for
patients with PPA. Although this has not yet been done, one way to utilize these findings would be to develop a treatment program in which patients are trained on early-acquired words and progress to re-learning later-acquired words. This is based on the training regimen used by Laganaro et al. (2006) to treat non-progressive aphasics, in which AoA predicted progress during therapy in one patient. The goal of the treatment would be to revive words that had become inaccessible since the onset of the disease. Data from Ukita et al. (1999) and Laganaro et al. (2006) give hope to patients for recovery from this seemingly uncontrollable degenerative disorder. However, further research must be done in order to see if patients are truly able to relearn early-acquired words when explicitly taught.

III. Conclusion

Overall, the findings of studies done on patients with PPA tell a more coherent story than studies addressing non-progressive aphasia. With the exception of patient EP in Hirsh and Funnell (1995), AoA consistently predicted naming performance in PPA patients in many studies. With regard to error analysis, omission errors are most closely associated with AoA (Hirsh & Funnel, 1995; Woollams et al., 2008). The most popular locus of AoA based on PPA data seems to be at the lexical-phonological level (Hirsh & Funnel, 1995; Lambon Ralph et al., 1998). However, there is still a debate as to whether the mental lexicon is a modular system or if it functions through a cascading process of activation, making it difficult to determine the place at which AoA exerts an effect. New avenues of treatment utilizing AoA should be explored, such as training patients on words that they failed to name at baseline.
Alzheimer’s Disease

Alzheimer’s disease, a type of dementia, is characterized by severe degeneration of neurons in the brain, causing deficits in thought, memory, and language, which interferes with daily activities. It is most common in individuals over the age of 65, but can also develop by age 40 or younger in some cases. Many aspects of Alzheimer’s disease are still a mystery, such as the specific causes and who is at the greatest risk for developing the disease. Some causes currently being researched include β-amyloid deposits (“plaques”) in the brain, which ultimately lead to death of the surrounding neurons, or possibly build-up of the tau protein which causes tangles amongst neurons, or breakdown of the myelin sheath of neurons. Prospective biomarkers of the disease being researched include cerebrospinal fluid, genetic markers, and brain imaging (Jeong, 2008).

In addition to the uncertainty of causes and risk factors, it is difficult to diagnose and distinguish between other types of dementia such as primary progressive aphasia. Patients suspected of having Alzheimer’s disease are often given a battery of cognitive tests and a brain scan in order to visualize any degeneration, but even then, the results are often not definitive and the only way to be sure of the underlying pathology is a post-mortem autopsy (Jeong, 2008). An accurate diagnosis must be made in order to effectively treat patients. Carefully analyzing the words produced by patients in cognitive tests could yield useful information that would lead to an accurate diagnosis. The following sections will investigate whether AoA can be used in part to determine whether an individual has dementia of the Alzheimer type and whether it can be used as an indicator of the type or severity of cognitive
deterioration. Finally, uses for AoA as part of a therapy regimen for sufferers of Alzheimer’s disease will be discussed.

I. Influence of Age of Acquisition

Patients with Alzheimer’s disease are often able to retrieve autobiographical information from the remote past, but have more difficulty retrieving memories from the recent past (Silveri, Cappa, Mariotti, & Puopolo, 2002). Based on this model, it is possible that semantic memory is degraded in these patients in a similar fashion, with later-acquired words being lost before early-acquired words. The studies presented in the following sections aimed to shed light on this AoA theory, as well as investigated whether AoA could be used as a reliable cognitive measure to aid in distinguishing normal age related cognitive decline from degenerative dementia due to Alzheimer’s disease.

Picture Naming

Using picture naming data from an earlier study (Taylor, Gilleard, & McGuire, 1996) on Alzheimer’s patients and patients with multi-infarct dementia, Taylor (1998) performed a re-analysis in order to investigate the effects of AoA on naming. If patients failed to name the drawing of an object by 15 seconds, they were instead asked to describe how it was used or what it was used for, in order to determine if it was a recognition or a naming problem, such that failure to describe the object would indicate a recognition error, and an accurate description of the object would instead indicate a naming deficit. Analysis of the results showed that AoA,
familiarity, and frequency were correlated with naming latency and recognition failure. Furthermore, using partial correlations, Taylor found that naming latency and recognition were correlated with AoA even when word frequency was controlled for. When AoA and familiarity were controlled for, frequency was significantly correlated with both naming latency and recognition failure, demonstrating that both AoA and frequency exerted independent effects, contrary to what was found by Morrison and Ellis (1995) in a written word recognition task given to healthy young individuals in which frequency became non-significant once AoA was controlled for.

Importantly, correlations with AoA when familiarity was controlled for and vice versa were all non-significant. This shows that AoA and familiarity are difficult to dissociate, requiring the use of multiple regressions to control for the strong intercorrelations, which the authors failed to do. AoA and familiarity were most strongly correlated with recognition failure, while naming latency was most dependent on frequency. Although the authors did not offer a theoretical explanation for their findings, it can be hypothesized that the correlation between AoA and recognition failure suggests a semantic locus for this variable, since there seems to be difficulty in activation of the concept. This would be concurrent with Brysbaert and Ghyselinck (2006)’s theory that an AoA effect emerges when a unique concept must be selected, thus placing the locus of AoA in the semantic system. Frequency, however, could be affecting multiple levels of processing in its influence on naming. Further analyses using a simultaneous multiple regression would help dissociate AoA and familiarity, in order to paint a clearer picture of separate effects of the variables. Another confounding factor of this study was the failure to separate the two patient
groups (Alzheimer’s disease and multi-infarct dementia). As was seen in aphasia, there were many subtypes within the disease, such as pure anoma, which could be separated from other types of aphasia in order to isolate specific psycholinguistic effects. Therefore, separating the patient groups in the current study could have yielded different results.

Kremin et al. (2001) also used a picture naming task to test eight French-speaking patients with Alzheimer’s disease. Using a multiple regression analysis, they found that AoA successfully predicted naming performance in five out of the eight patients. Name agreement predicted the same number of patients, and familiarity only predicted the performance of one patient. Although it is clear that AoA showed an effect on naming, the small sample size limits one from making reliable general conclusions.

Also employing the use of a picture naming task, Cuetos et al. (2005a) tested ten Spanish-speaking probable Alzheimer’s patients in order to see which psycholinguistic variables predicted naming accuracy and certain types of errors. Patients were tested twice, in order to observe changes in performance over time, with two years between each administration. As expected, the percent of correct answers dropped from 72.3% to 49.8% over the two years. A regression analysis showed that AoA was the only variable that significantly predicted accuracy both at the first and second evaluations.

With regard to the error analysis, semantic errors were the most abundant at the first evaluation. At the second evaluation, the largest percentage was comprised of no-response errors. The types of transitions were also analyzed, with the following
being the most common: from correct to semantic error, from correct to no-response, and from semantic error to no-response. AoA significantly predicted the change from correct to no-response and from semantic error to no-response. Although frequency and familiarity also predicted certain types of error transitions, AoA was the variable that best predicted changes in error. Furthermore, AoA also predicted the specific progression of errors. In other words, less severe errors (correct to a semantic error, for example) were predicted by early-acquired words, whereas more severe errors (such as semantic error to no-response) were predicted by later-acquired words.

The results of this study suggest that AoA is a good predictor of psycholinguistic processes during the course of the illness because it appears to be present throughout the cognitive deterioration of patients. In addition, it seems that semantic errors correspond to an earlier, less severe stage of the illness, while no-response errors indicate a more severe stage. Most importantly, AoA played a key role in predicting the changes in errors in the different phases of Alzheimer’s disease.

Supporting the theory of Brysbaert and Ghyselinck (2006), the authors hypothesized that AoA is acting at the connection between the conceptual system and the lexical level, meaning that early-acquired words have stronger connections than later-acquired words. Therefore, increased competition in the conceptual system led to large AoA effects which overshadowed frequency effects. The error pattern found in this study, that AoA strongly predicted no-response errors, but not semantic errors, is in concordance with Hirsh and Funnell (1995), but in direct opposition to Nickels and Howard (1995) and Cuetos et al. (2002), who found that AoA did in fact predict semantic errors. However, these studies were done on aphasic and PPA patients, and
not on patients with Alzheimer’s disease. Moreno-Martínez, Laws, Goñi-Imícoz, and Sánchez-Martínez (2008) conducted a nearly identical study to that done by Cuetos et al. (2005a), but over a period of one year instead of two, and they included healthy age-matched controls. They found that AoA, name agreement, and frequency predicted performance at the two testing periods, and name agreement was the only variable that predicted performance in the control group.

Using an experimental control method, Holmes, Fitch, and Ellis (2006) presented 22 Alzheimer’s patients with pictures of early- and later-acquired objects, interspersed with pictures of imaginary non-objects. Patients were first asked to classify the object as being real or fake, and then to name the real object. The authors included imaginary non-objects in order to assess AoA separately on object recognition (familiarity) and naming. In other words, the imaginary non-objects were included to specifically examine the patients’ ability to recognize objects. All real objects were matched on familiarity, word frequency, name agreement, visual complexity, imageability, word length in syllables, and proportion of living and nonliving objects, but differed on AoA. An analysis of variance (ANOVA) revealed that AoA was a significant predictor of naming success in the patient group, meaning that early-acquired items were named correctly more often than later-acquired items. The control group did not show an effect of AoA because their performance was already at ceiling. In looking at naming as a function of objects correctly recognized, the control group named significantly more of the objects they classified as real than did the patients, with an advantage for early-acquired words for both groups.
The types of errors made by the patients and controls were also recorded. The controls barely made any errors, although when they did, they were semantic in nature. Patients’ errors were of the semantic and no-response type, similar to the findings of Cuetos et al. (2005a). However, as expected, patients made many more errors overall than controls. Later-acquired items induced more of both types of errors than early-acquired words, suggesting that they were significantly more difficult for patients. This however, is in opposition to the influence of AoA found by Cuetos et al. (2005a), who showed that only no-response errors were predicted by AoA, and not semantic ones.

Since AoA was found to influence both object recognition and name retrieval, the authors favored a multiple loci account for AoA based on the ease of mapping between representations in the mental lexicon. Holmes et al. (2006) also recognize, however, that AoA may have a semantic locus since it influences the classification of real and fake objects by activating the correct semantic knowledge to make a decision. Their idea is concordant with the theory of Brysbaert and Ghyselinck (2006) because it implies that a unique concept had to be selected for and activated in this task. The fact that most of the errors made by patients were semantic in nature and were induced predominantly by later-acquired items, gives evidence for a primary locus of AoA in the semantic system. However, the ambiguity of the underlying cause or causes of no-response errors makes it difficult to isolate AoA to a single locus. Therefore, a multiple loci model for AoA is plausible. This study provides further confirmation (along with Taylor, 1998; Silveri et al., 2002; Kremin et al., 2001; Cuetos et al. 2005a; Moreno-Martínez et al., 2008) that AoA is important in
determining naming accuracy in Alzheimer’s disease, as well as showing that AoA also affects object recognition (not solely naming) in patients, which confirms earlier findings by Taylor (1998).

Rodríguez-Ferreiro et al. (2009) investigated the processing of grammatical class (i.e. nouns versus verbs) in Alzheimer’s disease patients. They administered a picture naming task to both patients and healthy age-matched controls consisting of 50 pictures of objects and 50 pictures of actions. Using the Linear Mixed Effects Models statistical approach to analyze their data, they found that controls were more accurate than patients in naming, and that the likelihood that a patient would produce the correct name was significantly predicted by AoA, frequency, and name agreement, but not grammatical class. Interestingly, scores on the Mini Mental State Exam (MMSE), a measure of cognitive deterioration, did not significantly predict performance. This gives further evidence that AoA is an important variable for detecting the subtle deficits of the disease, and that it could perhaps be more effective than the MMSE, a test specifically designed to test for deterioration of cognitive skills. Specifically, AoA could be useful for early detection and diagnosis of Alzheimer’s disease.

Types of errors were also recorded and analyzed. Controls performed close to ceiling, but did make some errors, which occurred mostly when asked to name actions rather than objects. The same pattern was found for patients, but to a much more severe degree, in that patients produced more types of errors and more errors overall. Semantic errors were the most common type for both patients and controls (similar to what Holmes et al., 2006 found), although controls also made a
considerable number of no-response errors. Based on the prevalence of semantic errors, the authors suggest that Alzheimer’s disease patients have a severe impairment in the lexical-semantic system, making it difficult to retrieve the appropriate name for a given picture, especially when the word is lower in name agreement, lower in frequency, and a later-acquired word. Rodríguez-Ferreiro et al. (2009) favored the semantic network theory of Steyvers and Tenenbaum (2005), which states that early-acquired words hold a more central position in the network and have more connections, making them better competitors in the process of lexical selection, leading to faster selection in healthy individuals and greater accuracy in patient populations. The results of this study give strong evidence for a semantic locus for AoA and are also concurrent with the semantic theory of Brysbaert and Ghyselinck (2006).

*Category Membership (Living versus Non-living)*

It has been found with relative consistency that Alzheimer’s patients show a difference in naming performance across living and non-living categories (e.g. Garrard, Patterson, Watson, & Hodges, 1998). However, the selective impairment has not been consistent: some patients have shown a deficit in naming living items, whereas others have more trouble with non-living objects. It is thought that the dissociation between these categories is the result of differential damage to certain brain regions, with the temporal lobe processing structural aspects (living) and the fronto-parietal lobe processing functional attribute (non-living; Silveri et al., 2002). However, the most common pattern found in the literature is that of impairments in
naming living things. Silveri et al. (2002) set out to investigate whether certain psycholinguistic variables, such as AoA can predict performance, as well as play a role in this category dissociation.

Testing 39 Italian-speaking Alzheimer’s patients and 12 age-matched and 20 young controls on a picture naming task consisting of 40 living items and 40 non-living items, Silveri et al. (2002) found that AoA, along with name agreement were the only two variables that predicted accuracy in patients. AoA did not significantly predict performance in either control group (most likely because the young controls performed at ceiling and the age-matched controls performed somewhat close to ceiling), but there was a trend in that direction. Patients also showed a significant category effect, naming non-living objects more accurately than living things. Age-matched controls did not show a significant category effect, but also showed a trend in that direction, and young controls did not show a category effect. AoA did not, however, explain the category dissociation observed in the patients, since the opposite would be expected: living kinds are usually acquired earlier than non-living things, and would hypothetically be better preserved if AoA influenced the organization of these categories. The category distinction between living and non-living things lies in their differential semantic networks (Silveri et al., 2002). Therefore, the fact that AoA failed to predict this dissociation gives evidence against a semantic locus in the mental lexicon for this variable. Although AoA predicted naming accuracy, based on the results of this study, it most likely did so at non-semantic loci.

Gale, Irvine, Laws, and Ferrissey (2009) also investigated the effect of category on naming performance on a picture naming task by testing patients and
age-matched controls. They considered AoA, but only as part of an undifferentiated group of “nuisance variables” and did not look at whether it influenced category membership effects. AoA, along with frequency, familiarity, and visual complexity accounted for 39% of the naming variance. The effect of category was also significant, with non-living items being easier to name than living items, but it only accounted for 3% of the variance in performance after controlling for the nuisance variables. This shows that the nuisance variables had a greater influence on naming than category membership, which provided more evidence for the importance of AoA (along with the other “nuisance variables”) in Alzheimer’s disease patients.

Interestingly, controls performed qualitatively similar to patients with regards to category, but patients were significantly worse overall. This suggests that the pathology is an exaggerated variation on the normal elderly naming pattern, which is quantitatively worse than young healthy control performance (Hodgson & Ellis, 1998).

**Semantic Fluency**

Alzheimer’s disease patients consistently show severe semantic deficits, which is demonstrated by poor performance on semantic fluency tests. Semantic fluency is analyzed as part of a verbal fluency task. For this task, individuals are given a category such as words beginning with the letter “s” (letter fluency) or the category “animal” (semantic fluency) and asked to write or say as many words they can think of from this category in a given time (usually 60 seconds; Curtis, Bullmore, Brammer, Wright, William, Morris, Sharma, Murray, et al., 1998). Patients’
performance on letter fluency is on par with age-matched controls, but they show a clear impairment in producing an adequate number of words, perseverate, and they demonstrate a loss of set (e.g. producing words for vegetables when asked for animals) in a semantic fluency test (Forbes-McKay, Ellis, Shanks, & Venneri, 2005). The psycholinguistic aspects of the words that they do successfully produce can be examined and compared to age-matched controls.

Forbes-McKay et al. (2005) recruited 96 Alzheimer’s patients, as well as 40 healthy age-matched controls, who were given a semantic fluency task in which they had to generate words for the categories of animals and fruit in one minute. Overall, they found that the controls produced more words than the patients. The analysis of the characteristics of the words produced revealed that patients produced significantly more early-acquired words than controls. Furthermore, discriminant function analyses revealed that the AoA of words generated correctly classified 88% of patients and 95% of controls. Other variables, such as the number of words produced, length, typicality, and frequency also predicted group membership, but to a lesser degree. Importantly, this study demonstrated that the words that Alzheimer’s disease patients produced were strongly influenced by AoA and that this unique characteristic could be used as one way to discriminate patients from healthy controls. It also suggested that AoA may have a semantic locus, since early-acquired words were more resistant to damage of the semantic system seen in Alzheimer’s disease. This evidence for a semantic locus contrasts the findings of Silveri et al. (2002), which showed that AoA was not associated with category membership, which is generally thought of as a semantic variable.
Naming-to-Description

Sartori, Lombardi, and Mattiuzzi (2005) found that AoA predicted naming performance in a naming-to-description task in which Alzheimer’s patients and healthy controls were given sentences with three semantic features in it, such as “has a handle, has two wheels and has two pedals”, and the target answer would be “bicycle”. However, semantic relevance (individual relevance values associated with each of the semantic features of the object or concept) emerged as an even more powerful predictor of accuracy than AoA. The authors noted that total relevance is high when AoA is low and frequency is high, and therefore, the semantic relevance of a concept is higher when it is acquired earlier in life. According to this view, later-acquired concepts (and their corresponding words) have lower semantic relevance, “as they have reduced occasions on which concepts are contrasted with similar items” (Sartori et al., 2005). Concepts and words that are acquired earlier, however, have been fine-tuned in terms of their most relevant features, making it easier over time to discern among similar concepts. Therefore, the findings from this study give evidence for a semantic or conceptual locus for AoA, which is again concurrent with the theory put forth by Brysbaert and Ghyselinck (2006), stating that larger AoA effects are found when one must tap into a unique concept in the semantic system.

Aiming to examine the role of features and feature dimensions in naming performance in Alzheimer’s patients, Marques, Cappa, and Sartori (2010) also chose to diverge from the standard picture naming task, and instead used a naming-to-description task. This task was chosen because it allows for easier manipulation of features in terms of semantic relevance, for example, compared to the picture naming
task. They argued that this could be an important variable in naming, since concepts are constructed from many types of features, such as sensory, motor, and functional. To complete the task, patients, healthy age-matched controls, and young controls were asked to provide a name corresponding to a given definition, which consisted of a feature type (sensory or nonsensory) and semantic relevance (high or low). Sensory features included color, visual form, and surface features, whereas nonsensory features were functional and consisted of definitions. For example, for the concept “strawberry,” “It is heart-shaped” is a sensory feature, and “Most frequent in spring” is a nonsensory feature. Both of these examples are of high semantic relevance. “You can grow it” would have low semantic relevance for “strawberry,” for instance. Importantly, the difficulty of this task prevented healthy individuals from performing at ceiling, eliminating possible statistical confounds that can arise from the control population mastering the task.

Overall, young controls correctly named the most objects (60.24%) with age-matched controls (46.64%) and patients (28.04%) trailing behind them. Semantic relevance contributed the most to naming accuracy, followed by nonsensory features, and sensory features. Partial correlations were used to examine effects of AoA and frequency on naming performance. When frequency was partialed out, AoA predicted naming performance in healthy young controls, age-matched controls, and patients. This study clearly showed that controls and patients exhibited a uniform pattern of decline that seemed to only differ quantitatively in the numbers of items they named correctly. Again, the data support the possibility of a semantic or a conceptual locus for AoA since the task used required access to the semantic system and was
influenced by AoA, which is in agreement with the theory of Brysbaert and Ghyselinck (2006). It should be noted that their theory was supported even though the task did not involve pictures. It is possible that in order to select the correct word from the given definition, subjects had to create a mental image of the object in order to select the correct concept and then retrieve the word for it. Overall, AoA still shows a robust effect even when the task used to assess naming is changed.

**Individual Data**

Although it is important in some cases to analyze patient data as a whole in order to find global trends of a given disease, it is also important to dissect the data into individual cases, which was found to be an important technique in aphasia (i.e. Hirsh & Ellis, 1994; Hirsh & Funnell, 1995). Minor and/or major differences between patients who are diagnosed with the same pathology can be elucidated by analyzing individual data. Cuetos, Rosci, Laiacona, and Capitani (2008) conducted a longitudinal study on two Spanish-speaking Alzheimer’s patients using a picture naming task. They wanted to see if the same psycholinguistic variables would predict naming performance over time, as their accuracy declines due to progressive degeneration. The first patient showed a clear decline in naming performance over time, dropping by 42%. AoA and frequency predicted performance at the first testing stage, as well as at the second testing stage, three years later. Therefore, AoA and frequency were the only psycholinguistic variables to consistently and reliably predict naming performance in Case 1. Furthermore, AoA was the only variable that predicted the *transition* of an item being named correctly to being named incorrectly.
Case 2 also showed a decline in performance over time, but it was less severe than that of Case 1. Although AoA predicted performance at stage 1 and stage 2, familiarity became the most powerful predictor at stage 2, contrasting the group findings of Cuetos et al. (2005a). Familiarity was also the only variable that significantly predicted the transition of a name from being correct to an error in Case 2, which sharply contrasted the pattern found in Case 1.

The authors offered three explanations for the patterns observed in this study. They suggested that the naming pattern observed in Case 1 could be explained by the fact that all of their high familiarity items had already been impaired at the time of stage 1 testing, thus allowing for AoA to have the greatest influence. The same logic could also be applied to Case 2. However, they deemed this explanation unlikely since, for example, the words produced by Case 2 in stages 1 and 2 had a similar mean AoA. Another possible explanation was that the respective starting points and rates of decline for each patient were influenced by different variables. Case 1 started with better performance than Case 2 at stage 1, but declined at a faster rate than Case 2. Once again, the authors dismiss this possibility because it would mean that AoA, for example, would have to exert an effect at accuracy levels from 63%-59%, and then familiarity takes over from 59% to 40%, and then AoA resumes its influence from 40% to 23%. The explanation that the authors favor is that the two patients had fundamentally different underlying impairments, which caused their naming performance to be differentially influenced by AoA and familiarity. Their disease took different paths, which once again illustrates the fact that patients falling under an overarching disease category can have different underlying deficits. Cuetos et al.
(2008) therefore proposed that the psycholinguistic characteristics of impaired words served as markers of degeneration path selectivity. Similar to Nickels and Howard (1995), Cuetos et al. (2008) showed the need for individual analysis in addition to group analysis of data.

In the analysis of errors, it was shown that Case 1 produced mostly no-response errors, whereas Case 2 produced almost equal numbers of no-response and semantic errors. Hirsh and Funnell (1995) suggested that familiarity effects are observed when the semantic system is impaired. The current study provides further evidence in favor of this idea since Case 2 made many more semantic errors than Case 1, and their performance was predicted by familiarity, showing that there is likely a semantic locus for familiarity. In terms of AoA, it is more difficult to draw conclusions about a particular locus since, as discussed previously, it is difficult to attribute no-response errors to a single problem in the mental lexicon. Again, it can be the result of an inefficient activation at the lexical level, failure of phonological retrieval, or failure to activate the correct concept (Kittredge et al., 2008).

These results can be compared to the study done by Cuetos et al. (2005a) in which the group data showed a tendency to progress from committing mostly semantic errors at the first testing stage and then to committing mostly no-response errors when tested two years later. Perhaps Case 1 produced mostly no-response errors because their disease was more severe, which is demonstrated by their rapid decline in naming accuracy compared to Case 2. Case 2, characterized by their almost equal production of semantic and no-response errors, was perhaps in a “transitional” stage of their illness in which it was increasing in severity. This hypothesis however,
does not correspond to the psycholinguistic predictor variables since Case 1’s performance was predicted by AoA at both points and Case 2 followed a different trajectory, being influenced by AoA at the earlier testing stage, and then being influenced by familiarity at the later stage, at which their illness had progressed considerably. Alternatively, it is possible that AoA is a predictor of severity of the course of degeneration (Cuetos et al., 2008). Case 1 showed a very steep decline in functioning, and was also associated with AoA. On the other hand, Case 2 was associated with familiarity and had a slower decline in naming accuracy. Further evidence for this idea comes from Cuetos et al. (2005a) who demonstrated that AoA, in addition to being the best predictor of changes in error, also predicted the progression of change in response according increasing error severity (i.e. correct to semantic error is less severe than semantic errors being replaced with no-response errors).

Neuroimaging

Attempting to provide more concrete evidence for AoA effects and its anatomical correlates in the brain, Venneri, McGeown, Hietanen, Guerrini, Ellis, and Shanks (2008) administered a semantic fluency test to Alzheimer’s patients and healthy age-matched controls and correlated their performance with grey matter density values from a 3D MRI scan, using the technique of voxel-based morphometry (only the patients were given the MRI scan). Their hypothesis was that lexical effects observed on semantic fluency tasks may be related to the progressive degeneration of areas of the brain that store semantic knowledge.
Twenty-five Alzheimer’s patients and twenty-five controls were given a semantic fluency task and asked to name animals and fruit. Using a one-way analysis of variance (ANOVA), it was shown that patients produced significantly fewer words than healthy elderly controls. In addition, the words the patients produced were early-acquired and higher in typicality. A discriminant function analysis showed that AoA and number of words produced significantly predicted group membership (patient versus control). Together, these two variables successfully classified 88% of the controls and 92% of the Alzheimer’s disease patients. The predictive power of AoA could be harnessed and used as a method for diagnosing individuals who are suspected of having Alzheimer’s disease.

In order to compare lexical retrieval performance with grey matter density, a multiple regression analysis was used. The results showed that higher AoA values were significantly correlated with grey matter density in the following brain areas: frontal regions bilaterally, the right parahippocampal, fusiform and lingual gyri, the left postcentral gyrus, and the culmen of the right cerebellum. As noted above, significant correlations were found bilaterally in frontal regions, suggesting that the underlying brain regions that give rise to AoA effects are widely distributed, and not restricted to the left language-processing hemisphere. Overall, the analyses suggest that atrophy of the medial temporal lobe contributes most to lexical deficits seen in early stages of Alzheimer’s disease.

An important limitation to this study that must be considered is the fact that the scans of patients’ brains were not compared to scans of healthy age-matched controls. Therefore, it cannot be ruled out that the differences seen in grey matter
density are simply the result of individual developmental variation in the size and functionality of components of the hippocampus which may exist independently of lexical abilities, or alternatively, these differences could predispose individuals to exhibiting differences in lexical performance. Either way, MRI data from age-matched controls would be helpful for drawing more concrete conclusions.

**Lexical Decision**

Picture naming is a demanding task requiring individuals to first recognize the picture and then to activate the correct word that accompanies the concept. Lexical decision is a slightly less taxing process in which individuals simply decide whether a word is real or fake. Often, subjects are presented with a string of letters and asked to judge whether it is a word or not by pressing a key. Cuetos, Herrera, and Ellis (2010) used a lexical decision task in which Spanish-speaking Alzheimer’s disease patients and age-matched controls were presented with four stimuli on each trial, consisting of one real word and three pronounceable non-words and asked to decide which word was real. Half of the given real words were early-acquired and the other half were later-acquired. The goal was to investigate whether the AoA of words predicted performance on lexical decision, given that it is an easier task than picture naming. Research has shown that lexical decision is relatively unaffected in the early stages of Alzheimer’s disease (Cuetos et al., 2003), but that performance on the task can be an indicator of the beginning stages of semantic degeneration since semantic representations are broadly activated during lexical decision (Cuetos et al., 2010).
An analysis of variance (ANOVA) was run using group (patients versus controls) as a between groups factor and AoA of words (early versus later-acquired) as a within subjects factor. This analysis revealed the following: patients made significantly more errors than controls on the task and the errors were committed mostly on later-acquired words for both groups. The interaction between group and AoA was also significant, with more of a difference between early- and later-acquired words in the patient group than in the control group. It is interesting to note that although controls performed close to ceiling, they still made a small number of errors, predominantly on later-acquired words. Additionally, patients’ MMSE scores correlated significantly ($r = 0.438$) with their overall score on the lexical decision task, but this correlation was only moderately strong. This demonstrates the need for another test, such as the use of AoA, to fully determine the level of severity of the disease.

Cuetos et al. (2010) suggested two models to explain the results from their study. They argued that Steyvers and Tenenbaum (2005)’s model of semantic richness and advantage for early-acquired words having more connections in the network than later-acquired words explains the loss of the ability to identify later-acquired words as real words by patients in this study. These later-acquired words had fewer connections in the network to begin with, and were therefore the first ones to be lost. The authors also described how their results could fit into Ellis and Lambon Ralph (2000)’s model. In this model, however, it is the connections between the nodes that become weakened with degeneration, leading to the inability to sufficiently activate semantic representations. Both theories are plausible based on these results.
Importantly, this study investigated the use of the lexical decision task on Alzheimer’s disease patients and demonstrated that AoA, along with this task, is effective in detecting the disease at its early stages, possibly leading to more effective treatment.

II. Clinical Relevance

The studies described above demonstrate that AoA has the potential to be used to diagnose patients, to determine the stage of severity, and to illustrate the progression of the disease based on the cognitive deterioration observed through word and picture naming tasks. Subtle changes in the semantic aspects of spontaneous speech and writing (such as producing overall more early-acquired words) could serve as a cognitive marker of pathological cognitive decline and aid in the early and differential diagnosis between Alzheimer’s disease and normal ageing-related cognitive decline.

The results from Cuetos et al. (2005a) suggested that AoA could be used to estimate the level of severity of cognitive deterioration in Alzheimer’s patients by predicting performance accuracy, as well as the types of errors and changes in error production. The change in performance over time was also investigated by Cuetos et al. (2008) who demonstrated that AoA could act as a predictor of the severity of the course of degeneration. Forbes-McKay et al. (2005) and Venneri et al. (2008) showed that AoA and number of words produced in a semantic fluency task were together able to predict the group membership of 88% of healthy elderly controls and an impressive 95% (92% for Venneri et al., 2008) of the patients. Again, AoA emerges
as a powerful tool that can aid in the diagnosis of Alzheimer’s disease by
differentiating between normal and pathological cognitive decline. Furthermore, these
distinctive lexical differences are detectable at the earlier stage of the disease (patients
in this study were classified as having “minimal” or “probable” Alzheimer’s disease
in Venneri et al., 2008), which allow for a more efficient diagnosis and treatment
regimen. One reason that lexical influences can be detected at very early stages of
illness is because semantic knowledge is widely distributed throughout the brain.
Therefore, these subtle deficits many only be revealed by detailed analysis of
linguistic abilities (Venneri et al., 2008). This has important implications for the
healthcare industry because administering a verbal fluency task would be much more
cost-effective than some of the current tests used, such as gathering blood samples
and conducting brain scans.

Cuetos et al. (2010) showed that lexical decision, a slightly less demanding
task than picture naming, could be used to detect early stages of linguistic decline.
AoA effects were also observed during their lexical decision task, providing further
evidence for AoA being an important tool in Alzheimer’s disease diagnosis. The
ability to detect the disease at earlier stages is a powerful tool both in initiating a
treatment and rehabilitation regimen, as well as preparing the family members and
friends of the patient for the unfortunate decline of their loved one.

III. Conclusion

Unlike the story told by aphasic patients, the one that unravels through
examining Alzheimer’s disease patients shows a clear and robust role for AoA in
various language and recognition tasks. Significant effects of AoA on picture naming were shown in numerous investigations (Taylor, 1998; Silveri et al., 2002; Kremin et al., 2001; Frol et al., 2001; Cuetos et al., 2005a; Moreno-Martinez et al., 2008; Holmes et al., 2006; Cuetos et al., 2008; Rodríguez-Ferreiro et al., 2009), and AoA effects were also found in naming-to-description tasks (Silveri et al., 2002; Sartori et al., 2005), lexical decision (Cuetos et al., 2010), and semantic fluency (Forbes-Mckay et al., 2005; Venneri et al., 2008). Importantly, semantic fluency, along with AoA was shown to be an effective predictor of group membership (patient versus control) and therefore emerges as a potential tool for diagnosing individuals exhibiting symptoms of cognitive decline. AoA was also shown to be a possible predictor of the level of severity of cognitive degeneration, as well as the severity of the course of the illness (i.e. Cuetos et al., 2005a; Cuetos et al., 2008). With regard to a locus for AoA, it seems that it at least resides partially in a semantic locus given the prevalence of semantic errors in patients (Cuetos et al., 2005a; Holmes et al., 2006; Cuetos et al., 2008; Rodríguez-Ferreiro et al., 2009) and the robust effects of AoA found in tasks that demand access to the semantic system (i.e. Forbes-Mckay et al., 2005; Sartori et al., 2005).
**Dyslexia**

Dyslexia refers to a difficulty in reading which can either be **developmental**, meaning the disability is present when a child first begins to read and spell, even though they exhibit normal general, social, and emotional intelligence, or dyslexia can be of the **acquired** type, meaning that an adult who was formerly a fluent reader develops the disability after brain damage (Baddeley, Logie, & Ellis, 1988). It is generally agreed upon by psychologists that there are at least two processing routes for reading a word: a lexical route by which words are treated as a whole, and a sub-word-level (SWL) route which is based on grapheme-to-phoneme rules. In a language with shallow orthography (transparent; meaning there is a consistent spelling-to-sound correspondence, such as in Italian), the SWL route is preferred since this method is faster (Toraldo, Cattani, Zonca, Saletta, & Luzzatti, 2006). English is an example of a language with deep orthography (non-transparent), meaning that many words have an inconsistent spelling-to-sound correspondence.

Acquired dyslexia is divided into categories of different types which reflect the different patterns of reading errors observed. One type, **phonological dyslexia**, is characterized by the ability to name regular and irregular words that are written in an orthographically familiar manner, and the inability to read non-words. Phonological dyslexia is usually the result of a disruption to the SWL reading route (Gerhand, 2001; Toraldo et al., 2006). Another type of acquired dyslexia, **deep dyslexia**, is defined by the ability to extract the meaning from a word while still being unable to read the word out loud. Another characteristic is the tendency to make semantically related errors in the oral reading of single words such as saying “canary” in place of
“parrot”. Individuals with deep dyslexia have more difficulty reading orthographically regular non-words than real words, function words than content words, words with low imageability, and are unaffected by word length and spelling regularity (Baddeley et al., 1988). They also show better reading performance on nouns than verbs or function words (Toraldo et al., 2006), and show a profound concreteness effect (Barry & Gerhand, 2004). Deep dyslexia is sometimes categorized as a subtype of phonological dyslexia. Surface dyslexia, yet another type of dyslexia, is the opposite of deep dyslexia in that individuals are unaffected by lexicality, parts of speech or imageability, but are instead affected by word length and spelling or orthographic regularity (Baddeley et al., 1988). Surface dyslexia is thought to be the result of damage to the lexical reading route (Gerhand, 2001; Toraldo et al, 2006).

Another type of dyslexia called pure alexia (also known as letter-by-letter (LBL) dyslexia) is characterized by the ability to identify and name single letters, but a persistent inability to read effectively. Parallel processing of letters is absent in these individuals who show a profound effect of word length, with longer words being much more difficult to read, since each letter is processed separately. Interestingly, spelling, writing, speaking, and listening comprehension, as well as other cognitive processing abilities, are normal (Cushman & Johnson, in press). This deficit usually results from a lesion to the left fusiform gyrus and Visual Word Form Area, an area of the brain thought to be involved in word recognition (Cohen, Martinaud, Lemer, Lehericy, Samon, Obadia, Slachevsky, & Dehaene, 2003). Paralexia (also known as visual dyslexia) has been debated as to whether it can be
considered a distinct subtype of dyslexia. It is characterized by “visual confusions” in which “was” is read as “saw”, for example (Lambon Ralph & Ellis, 1997). Some studies also refer to a type of dyslexia called **undifferentiated dyslexia** in which their pattern of reading cannot be distinctly classified into any of the types mentioned above (Toraldo et al., 2006). A fundamental question relating to dyslexia is whether the same underlying deficits give rise to both developmental and acquired dyslexias. Exploration of the lexical variables that affect reading in patients with dyslexia could help to answer this question.

**I. Influence of Age of Acquisition**

Individuals with acquired deep dyslexia and developmental dyslexia show a profound difficulty in reading words with low imageability (Baddeley et al., 1988) and concreteness (Gerhand and Barry, 2000). However, this conclusion was made without controlling for AoA. It is therefore be important to investigate whether AoA effects are observed in dyslexia and whether they can account for the imageability and concreteness effects found in many studies.

**Developmental Dyslexia**

Baddeley et al. (1988) set out to examine the reading patterns of children with developmental dyslexia and how they compared with two control groups, one matched on chronological age, and the other matched on reading age. Their goal was to investigate whether the naming patterns exhibited by children with developmental dyslexia and normal reading patterns resemble those found in individuals with different types of acquired dyslexia. This would give evidence for whether common
deficits underlie all types of dyslexia. Using an analysis of variance (ANOVA), Baddeley et al. (1988) showed that AoA had a clear effect on both the dyslexics and the reading age controls, meaning that they found later-acquired words significantly more difficult to read than early-acquired words. Interestingly, the imageability effect was significant, but very weak. It is possible that the dampened influence of this variable could be due to the fact that AoA was controlled for.

Ultimately, the patterns found in the developmental dyslexics (difficulty pronouncing non-words, difficulty with non-regular orthography or spelling, effects of AoA, imageability, and word length) could not be meaningfully related to either surface or deep acquired dyslexia. Rather, there is a striking similarity between the reading pattern of dyslexics and their reading age controls, suggesting that the reading pattern observed in developmental dyslexics might be expected during the normal, non-pathological, development of reading. In other words, the difference between developmental dyslexia and normal reading develop is quantitative, rather than qualitative. It should be noted, however, that this is the only known study that investigated AoA in individuals with developmental dyslexia. Therefore, more research should be conducted in order to draw more confident conclusions about the disorder. The case of acquired dyslexia is different from developmental dyslexia because individuals with the disability exhibit normal reading patterns before the occurrence of brain damage which ultimately leads to reading problems. Investigation of the lexical variables that affect reading in acquired dyslexics will be important for inferring what their underlying impairments are.
**Acquired Dyslexia**

*Paralexia*

Attempting to further investigate paralexia and determine whether it can be considered its own subtype of acquired dyslexia, Lambon Ralph and Ellis (1997) conducted a case study on an 80 year old woman (AB) who exhibited symptoms of aphasia, memory loss, and reading difficulties. Using a battery of tests to assess speech processing and comprehension, the authors found that over 90% of AB’s reading errors could be classified as visual in nature. In addition, she showed evidence for a phonological impairment because she exhibited difficulty repeating words and non-words. Poor performance on word-picture matching tasks also suggested a central semantic deficit. AB was administered a number of word reading tests to assess which psycholinguistic variables influenced her performance. After entering in the results of these tests into a logistic regression, the authors found that AoA, imageability, and frequency all exhibited significant independent effects on reading. However, as pointed out by Ellis et al. (1996), it is difficult to draw definitive conclusions from regression data on a single case study.

Since AB displayed such a wide range of deficits, from phonological, to orthographic, to semantic, it is difficult to say which of these loci were specifically influenced by AoA. However, the authors do offer a few possible mechanisms by which AoA acts. First, it is possible that reduced or noisy visual input, together with a diminished contribution from semantics, in turn reduced the level of activation of phonological representations. This, combined with poor activation of phonological representations due to late AoA and low frequency, could have led to undirected
spreading activation in the visual input lexicon (a module that stores the visual representation of familiar words; Carlesimo, Fadda, Sabbadini, & Caltagirone, 1994), causing the activation of incorrect lexical entries, and thus leading to error production. This view assumes that AoA acts at the phonological level. Alternatively, AoA may influence the visual input lexicon such that later-acquired representations may be more difficult to access because they have been degraded from cerebral damage, whereas early-acquired representations remain intact.

Deep Dyslexia

Another single case study was conducted by Gerhand and Barry (2000) on a 52 year old patient (LW) with acquired deep dyslexia and Broca’s aphasia. A series of tests given to LW revealed that she had difficulty reading words and was unable to correctly read any non-words. Her comprehension was relatively normal, however, as shown by a synonym-matching task. In a further analysis of her semantic processing abilities, it was shown that she most likely had a mild impairment at this locus. LW was presented with 300 words to read aloud over four testing sessions in order to investigate the effects of AoA, frequency, concreteness, and word length. A multinomial logistic regression showed that AoA, concreteness, and word length predicted LW’s reading responses, whereas frequency failed to reach significance. A breakdown of the errors produced by LW demonstrated that the majority of her errors were semantic in nature, second only to omission errors. Furthermore, when LW committed a semantic error, the words she chose were generally early-acquired, shorter, and of a higher frequency. AoA seems to play a role in the process that leads to the production of semantic errors. It is possible that AoA was acting at the
semantic level, such that the semantic representations of early-acquired words were more easily activated than later-acquired ones. As stated previously, it is difficult to pinpoint the underlying cause of omission errors. One possible mechanism put forth by Gerhand and Barry (2000) is that AoA affects the strength of the connections between semantic representations and phonological output, such that if the phonological representation receives insufficient activation from the semantic system, then an omission could result. However, this mechanism does not explain the occurrence of semantic errors. Caramazza (1997) hypothesized that if the proper phonological representation fails to reach threshold, then spreading activation within the semantic system could lead to the production of a semantic error. Thus, semantic representations for later-acquired words would be less likely to be activated, leading to the production of early-acquired words, which is concordant with the finding that LW produced early-acquired words when she made a semantic error on a later-acquired word.

LW was re-examined by Barry and Gerhand (2003) in order to further investigate the effects of AoA and concreteness and a possible interaction between the two. They first investigated speech production in a single word reading task and found that AoA had a significant overall effect on reading performance. Further analysis showed that there was a significant effect of AoA specifically on concrete words, and not on abstract words. In order to assess her word comprehension abilities, Barry and Gerhand (2003) administered a two-part comprehension test in which LW was given a spoken definition of a word from a dictionary and asked to point to one of four words that she thought corresponded to the definition. In the first “unrelated”
part of this test, the four words were selected randomly, whereas in the second “related” part, each target word was presented with three related distractors that were similar in meaning, without being alternative matches. For example, if the target word was “mist” the related distractors would be “smoke,” “rain,” and “breeze.” LW performed relatively well on the unrelated part, and much poorer on the related condition, but did score above chance. A multiple regression analysis revealed that AoA was not significant in determining performance on the word comprehension tasks, but rather concreteness emerged as the only significant predictor.

Barry and Gerhand (2003) hypothesized that AoA has a major locus at the speech production system, specifically at the stage of retrieval of lexical phonology, since AoA effects were found on oral reading accuracy, but not on comprehension performance. This interpretation aligns with Morrison and Ellis (2000)’s “phonological completeness” hypothesis, which states that later-acquired words are more difficult to retrieve than early-acquired words. It also calls into question the connectionist model put forth by Ellis and Lambon Ralph (2000) in which AoA has an effect on all lexical tasks.

In a further analysis of LW’s reading patterns, Barry and Gerhand (2004) aimed to examine AoA and concreteness effects once again, but this time using a semi-factorial design. They had difficulty in compiling sets of words that varied on AoA and held concreteness completely constant and vice versa. As a result, they had problems finding any significant effects due to the variables being so interrelated, as well as LW performing at floor on the reading task. As a solution to this methodological roadblock, Barry and Gerhand (2004) presented LW with 80 pictures,
asked her to name them, and then conducted a multiple regression analysis on the data in order to overcome the problems with intercorrelations between variables in the semi-factorial design. Using this method, they found that AoA was the only variable to have a significant effect on naming.

Overall, combining the data on LW from multiple studies, it seems that AoA affects word production (as assessed by word and picture naming), but not comprehension in LW, and her semantic error responses were mostly early-acquired words. Although the authors of these studies come to the conclusion that AoA has an influence on speech production and phonology, it should be noted that when LW made semantic errors, they were mediated by AoA. Therefore, AoA cannot be so quickly given a single role in phonological speech production, and a more comprehensive model might place AoA influences in the connections between semantic and phonological representations.

**Pure Alexia**

Pure alexia, a significantly different type of dyslexia than the ones previously investigated, arises from damage to the Visual Word Form Area, thereby resulting in impairment in low-level, bottom-up processing of letter forms. Cushman and Johnson (in press) investigated this type of dyslexia by analyzing the reading patterns of a pure alexic patient, GJ, by using eye-tracking methodology. Eye-tracking was used in order to simulate a more natural reading situation (reading sentences), rather than the single word reading tasks used in other studies. The goal was to examine whether AoA affects reading through a top-down processing mechanism since past literature
(i.e. Johnson and Rayner, 2007) has shown that word frequency affects reading in patients with pure alexia. Unfortunately, these past studies failed to control for AoA.

Cushman and Johnson (in press) used a semi-factorial design in which they selected early- and later-acquired words while controlling for lexical frequency, cumulative frequency, imageability, and concreteness. The eye-tracking data revealed that both age-matched healthy controls and GJ showed an AoA effect while reading sentences. GJ made significantly more fixations and spent more time on later-acquired words than early-acquired words. Compared to the control population, the difference between later- and early-acquired words in terms of number of fixations and total fixation duration was significantly larger. Therefore, AoA, a higher-order lexical variable, did have a profound effect on GJ’s ability to visually process words in a sentence reading task by helping to compensate for damaged bottom-up letter form information through a top-down influence.

_Dyslexia in Other Languages_

The studies discussed thus far have looked at English-speaking dyslexic patients. The English language has a relatively irregular or non-transparent orthography, meaning that some words cannot be pronounced correctly just by sounding out the letter string. As a result, it is thought that English requires two reading routes, a lexical route and a sub-word-level (SWL) route. However, languages with shallow orthography, such as Italian, rely mostly on the SWL route for word production, but can recruit the lexical route for the relatively few non-shallow words that exist in the language.
Toraldo et al. (2006) aimed to examine dyslexia in a language with shallow orthography by studying Italian-speakers. They specifically studied aphasic patients with a single-word reading task consisting of words and non-words to determine which type of dyslexia they displayed and whether their lexical or SWL reading route was more severely affected. They also wanted to explore the effect of various psycholinguistic variables, such as AoA, on reading in dyslexic patients. In examining the distribution across dyslexic types according to type of aphasia, they found that almost all of the non-fluent aphasic patients suffered from phonological dyslexia, whereas the fluent aphasic patients were distributed more evenly across dyslexia types, with surface dyslexia only occurring exclusively in fluent aphasics. Toraldo et al. (2006) classified only one patient as having deep dyslexia in their study. Since significant AoA effects have been found in individuals with deep dyslexia (i.e. Gerhand & Barry, 2000; Barry & Gerhand, 2003; Barry & Gerhand, 2004), they decided to investigate this effect on their entire group of dyslexics. Interestingly, AoA was not significant for the one patient with deep dyslexia, which is in contrast with past studies (Barry & Gerhand, 2003; 2004; Gerhand & Barry, 2000). There was, however, a significant effect of AoA on phonological dyslexia patients, as well as on undifferentiated dyslexic patients. Finally, there was no significant effect of AoA on surface dyslexic patients. Also, introducing AoA as a predictor variable reduced the size of the other lexical effects (i.e. word frequency), rendering them insignificant. The authors also evaluated the effects of AoA on reading performance on a case-by-case basis in addition to the group analysis. They found that AoA significantly predicted the performance of 12 patients out of 90. Based on the fact that
AoA had the largest effect on patients with phonological and undifferentiated dyslexia, Toraldo et al. (2006) adopted the same theory as Gerhand and Barry (2003) in postulating that AoA affects the phonological output lexicon.

On the other side of the spectrum is Chinese, a language in which there is a strong arbitrary relation between logographic characters and their pronunciations. According to the arbitrary mapping hypothesis (Zevin & Seidenberg, 2002), one would expect to see larger AoA effects in a language with arbitrary orthography to phonology mappings. Law, Wong, Yeung, and Weekes (2008) investigated single word naming in a Chinese-speaking dyslexic patient, FWL. Although the patient was not diagnosed with a specific type of dyslexia, she exhibited severe semantic deficits, as well as some phonological disruptions. FWL was given 260 Chinese characters to read aloud. A simultaneous multiple regression clearly showed that AoA was the most powerful predictor of reading performance in both the patient and in an age-matched healthy control group. A more in depth post hoc analysis using a two-way analysis of variance (ANOVA) showed that there was a significant interaction between phonological consistency and AoA, meaning that FWL’s reading accuracy was essentially unaffected by phonological consistency when a character was learned early, but that she had significant difficulty with characters that were later-acquired and of low phonological consistency. The finding of AoA effects in Chinese is in line with the arbitrary mapping hypothesis, which states that AoA resides in the connections between the different levels of representation. However, a semantic locus for AoA cannot be ruled out since FWL also showed severe semantic deficits. These semantic errors could be accounted for by taking a connectionist approach (i.e. Ellis
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& Lambon Ralph, 2000) by theorizing that AoA influences the connections between many levels of representation (including semantic ones), which also encompasses the arbitrary mapping hypothesis.

In a study similar to that of Law et al. (2008), Law and Yeung (2010) examined the reading pattern of TWT, a patient with probable acquired deep dyslexia. They administered the same task to TWT that Law et al. (2008) used and found that once again, AoA and phonological consistency were significant predictors, along with semantic transparency (how related the meaning of a character is to that associated with its semantic radical; a semantic marker on Chinese characters). Furthermore, AoA and semantic transparency significantly discriminated semantic errors from other errors. However, the characters on which TWT committed a semantic error were actually early-acquired, rather than later-acquired, which is in direct contrast to the findings of Gerhand and Barry (2000). The involvement of AoA in semantic error production suggests that it exerts an influence at the semantic level. The difference in AoA effect on semantic error production between Law and Yeung (2010) and Gerhand and Barry (2000) could be explained by the fundamental differences between the English and Chinese languages. For example, Chinese characters with a higher semantic transparency are more prone to semantic errors because characters sharing the same semantic radical tend to be similar in meaning, thus activating an orthographic and semantic cue, leading to possible semantic confusion. Characters with higher semantic transparency are usually early-acquired in Chinese. This relationship does not exist in English. Overall, the explorations of dyslexia in
Chinese-speaking patients suggest that AoA exerts an influence at multiple levels, most likely supporting a connectionist approach.

II. Clinical Relevance

A study conducted by Smith-Spark and Moore (2009) on the processing of familiar faces in individuals with dyslexia suggests a role for AoA in diagnosis. Dyslexics and controls were presented with 50 pictures of familiar celebrities’ faces and asked to name them. Twenty-five of these were early-acquired, and the other twenty-five were later-acquired, and they were all matched on measures of familiarity and facial distinctiveness. An analysis of variance (ANOVA) was done with participant group as the between-participants factor and AoA as the within-participants factor. The analysis revealed that in both groups, early-acquired celebrities were named faster and more accurately than those who were later-acquired. Dyslexics and controls produced similar mean reaction times and levels of accuracy when naming celebrities were indistinguishable between the dyslexia group and the control group. Interestingly, there was an interaction between the participant group and AoA: the control group showed an early-acquired advantage of a greater magnitude than the dyslexia group. These data suggest that dyslexics may represent information differently from controls, although their performance is indistinguishable in terms of reaction time and accuracy. Thus, AoA could be an important tool in determining if an individual has dyslexia by expanding the diagnosis criteria through using non-conventional tasks for dyslexia such as face recognition.
Studies mentioned earlier (i.e. Laganaro et al., 2006; Ukita et al., 1999) showed promise in treating aphasic patients with a computer program designed to train patients on words that they had failed to name at baseline, and that it is possible for words to be revived over time. Training dyslexic patients on early-acquired words they failed to name at baseline first and then progressing to later-acquired words could also be beneficial since often times aphasics have dyslexia as one of their impairments. This treatment regimen would hopefully fortify their weak semantic, lexical and/or phonological connections or representations, and improve their reading abilities.

III. Conclusion

All of the studies reported in this section not only demonstrated an effect of AoA on single word naming, picture naming, and sentence reading during eye tracking, but many showed that AoA was the most powerful predictor variable for performance. Although AoA shows a clear effect in dyslexic patients, it is important to note that it is also a well-established effect found in healthy adults in many types of tasks (Juhasz, 2005). In the case of pure alexia, the patient exhibited quantitatively larger AoA than the healthy control group, suggesting that his pathology forced him to rely more heavily on AoA than normal (Cushman & Johnson in press). With regard to a locus for AoA, these data do not tell a conclusive story. Some argue for a phonological locus (Lambon Ralph & Ellis, 1997; Barry & Gerhand, 2003; Toraldo et al., 2006), some argue for an effect on the semantic system (Gerhand & Barry, 2000; Law & Yeung, 2010), and some argue for an effect at the connection between the representations and the arbitrary mapping hypothesis as part of the connectionist
approach (Law et al., 2008). Based on these findings, it seems that AoA affects multiple levels of processing, most likely by influencing the connections between representations. Studies on the patient LW (i.e. Gerhand & Barry, 2000; Barry & Gerhand, 2003; Barry & Gerhand, 2004) and the effect of arbitrary mappings found by Law et al. (2008) give the best support for this theory. Finally, Smith-Spark and Moore (2009) suggested that AoA could be an indicator of a differing representational organization in dyslexic patients compared to healthy individuals, and that this could be useful in diagnosis. Mirroring the possible treatments for aphasic patients on dyslexic patients could also be potentially beneficial.
Dysgraphia

Dysgraphia, a disorder characterized by poor spelling, can be either developmental or acquired (a result of brain damage). This section will explore the naming profile of a type of acquired dysgraphia called surface dysgraphia, as well as graphemic buffer disorder. Individuals who suffer from surface dysgraphia have impaired spelling of words that have atypical sound-to-spelling correspondences, such as “yacht”, which is often spelled “yot” by patients with this disorder (Weekes, Davies, & Parris, 2003). However, patients are often able to spell words with shallow orthography correctly, such as “dog,” since they can effectively rely on phonology to spell. Thus, phonological errors are most common when patients are trying to produce words with atypical spelling.

Surface dysgraphia is interpreted using two models: the “triple route” model and the interactive activation (IA) model. The “triple route” model consists of one nonlexical rule-based route in which the correct spelling will be produced only if the words are of typical sound-to-spelling correspondences, and errors result if the word has an atypical sound-to-spelling correspondence. This relies on phonology. The second route is comprised of a lexical or lexical-semantic spelling system that can spell typical and atypical words, but not non-words. Finally, the third route allows access to lexical orthographic representations for output directly from phonological input, while bypassing semantic representations. Therefore, according to this model, surface dysgraphia results from selective impairment to the lexical and lexical non-semantic routes, thus forcing the individual to use the first, phonological route, which results in phonological errors (Weekes et al., 2003).
The IA model is different from the triple route model in that it includes the semantic system. Information about sound-to-spelling and spelling-to-sound correspondences is distributed among connection weights in a network in which semantic, orthographic, and phonological units are connected to each other. Atypical words are thought to have weaker connections in these networks than typical words, thus making them more difficult to spell. Graham, Patterson, and Hodges (2000) found that atypical words with higher frequency have an advantage over those with a lower frequency, and are spelled correctly as often as typical words. AoA, however, was not controlled for, which will be discussed below. The IA model seems to give a better explanation of surface dysgraphia by including the semantic system because there is evidence of a correlation between semantic impairment and surface dysgraphia as shown by patients with semantic dementia (Hodges, Patterson, Oxbury, & Funnell, 1992).

Individuals with graphemic buffer disorder also show impairment in spelling words and non-words, and are particularly affected by word length in letters, such that the longer a word is, the less likely it will be spelled correctly. Common errors include substitution, omission, addition, and movement of letters that affect the middle of words, more so than the beginning or end of words. Graphemic buffer disorder is usually the result of a stroke that affects regions of the temporal and parietal lobes of the left hemisphere. In the process of spelling, it is thought that the “graphemic buffer” mediates the parallel processing of phonological and semantic representations of words such that the correct grapheme (a fundamental unit of written language which corresponds to a single phoneme) is chosen for a correct
spelling of a word. Therefore, individuals with graphemic buffer disorder have a damaged “graphemic buffer” which leads to errors involving letter confusion or omission (Sage & Ellis, 2004). An important distinction between the two types of dysgraphia describe above is that unlike patients with graphemic buffer disorder, patients with surface dysgraphia tend to produce mostly phonologically plausible errors when spelling, such as NEPHEW → NEFFUE, whereas individuals with graphemic buffer disorder have a tendency to make phonologically impossible errors.

I. Influence of Age of Acquisition

Surface Dysgraphia

Weekes et al. (2003) conducted a case study on an individual (MK) who developed surface dysgraphia after contracting herpes simplex viral encephalitis (HSVE), which caused damage to his left temporal lobe. The authors wanted to follow up on the finding of Graham et al. (2000) that word frequency influences spelling accuracy in patients with surface dysgraphia, by investigating possible effects of AoA. In addition to fulfilling the traditional criteria of surface dysgraphia (i.e. his spelling of typical words is better than his spelling of atypical words), MK had anomia.

The first of three experiments consisted of a task in which MK was read a list of words and was asked to write down each word on a blank sheet of paper. A logistic regression was performed to analyze the following variables: AoA, frequency, familiarity, and word length. AoA was the only variable that had a significant effect on spelling performance. In the second experiment, Weekes et al. (2003) used a semi-
factorial design in which they investigated spelling, picture naming, and word repetition. AoA was varied in the first condition and frequency was kept constant, and AoA was held constant in the second condition while frequency was varied. An analysis of variance (ANOVA) showed a significant effect of AoA for spelling and picture naming, but not repetition, meaning that early-acquired words were spelled and named more accurately than later-acquired words. No significant effects of frequency were found, suggesting that frequency effects found by Graham et al (2000) were actually AoA effects.

In the third experiment, the variable of predictability was investigated alongside AoA. Weekes et al. (2003) suggested that AoA effects may be confounded by declining predictability for later-acquired words. They defined a predictable stimulus as a written word containing phonological components that could be spelled in only one correct way in English, and an unpredictable stimulus as a written word containing phonological components that could be spelled in many ways in English. A fully factorial design was used to explore predictability and AoA in which one group contained words with predictable sound-to-spelling correspondences and the other group contained unpredictable sound-to-spelling correspondences. These stimuli were then divided into two more groups that were either early-acquired words or later-acquired words. Once again, MK was asked to spell these words as they were read to him. An ANOVA showed a significant overall effect of predictability, but no effect of AoA. A simple effects analysis showed that AoA was significant for unpredictable words, but not for predictable words.
Both models of spelling (triple route model and IA model) can account for the characteristics of MK’s spelling errors, as he seems to rely on intact phonological representations to spell from dictation. Most importantly, however, the significant interaction between predictability and AoA provides strong support for the arbitrary mapping hypothesis (Zevin & Seidenberg, 2002). That is, an effect of AoA should be observed on spelling unpredictable words because they have arbitrary sound-to-spelling mappings, whereas little or no effect of AoA should be observed on spelling predictable words because they have formulaic sound-to-spelling mappings. The results of the third experiment give clear evidence for the arbitrary mapping hypothesis since the spelling of unpredictable words was maintained, so long as the words were early-acquired. Additionally, selective training of later-acquired words could be used in rehabilitation of patients with surface dysgraphia.

**Graphemic Buffer Disorder**

Patient BH was diagnosed with graphemic buffer disorder, along with aphasia and other impairments after a stroke which led to widespread damage throughout her fronto-temporal, parietal, and occipital regions of the left cerebral hemisphere. A logistic regression analysis was conducted by Sage and Ellis (2004) on 611 items that she spelled over the course of three years. AoA was found to be a significant predictor of spelling accuracy, along with imageability, word length, word frequency, and number of orthographic neighbors (the number of words of the same length that differ by a single letter; Sage & Ellis, 2004). The authors suggested that damage to the links between semantics and orthographic word forms, or the graphemic output
lexicon, could explain the effect of AoA on BH’s spelling performance. It follows that early-acquired words have more robust representations than later-acquired words, putting them at a higher activation, according to the model proposed by Ellis and Lambon Ralph (2000) in which words entered into the neural network are likely to have stronger connections than those entered later. Therefore, the stronger connections between semantics and the graphemic output lexicon for early-acquired words will result in stronger activation of the graphemic buffer, such that the correct component letters of the target word are chosen. Later-acquired words fail to activate the graphemic buffer to the same degree, resulting in the incorrect component letters being chosen and ultimately, misspellings (Sage & Ellis, 2004). This study provides evidence for a locus of AoA at the connections between representations and gives further support for connectionist models such as that proposed by Ellis and Lambon Ralph (2000). Since arbitrary mapping has been shown to be an important component of connectionist models, it would be interesting to administer to patient BH the same task given to MK (Weekes et al., 2003) with predictability and AoA as manipulated factors. One would expect to see a larger AoA effect when spelling is unpredictable.

II. Clinical Relevance

The findings from the experiments done by Weekes et al. (2003) that AoA has a significant effect on spelling performance, and that unpredictable words are successfully spelled so long as they are early-acquired, suggest that AoA could be an important tool in rehabilitation. A future therapy involving training patients with surface dysgraphia on spelling later-acquired words could be beneficial because it
may strengthen the arbitrary mappings between phonology and orthography over time, leading to more accurate spelling. Training later-acquired words could also be useful for patients with graphemic buffer disorder through the strengthening of connections between semantic representations and the graphemic output lexicon. Further exploration in clinical applications must be done since little is known about dysgraphia.

**III. Conclusion**

AoA has been shown to have a strong and significant effect on spelling in patients with surface dysgraphia and graphemic buffer disorder. Although these disorders have very different profiles, words that are early-acquired tend to result in better spelling performance in both cases. Based on the two studies described above, this influence either lies in the arbitrary mappings between orthography and phonology in the case of surface dysgraphia, and in the connections between semantic representations and orthographic word forms in graphemic buffer disorder. Overall, AoA appears to have an important top-down influence on the simple process of spelling a word. In addition, training patients with dysgraphia on the spelling of later-acquired words may lead to improvement through the strengthening of the connections between semantics and the graphemic output lexicon or connections between orthography and phonology. Future studies examining dysgraphia will be necessary for a better understanding of the impairment since only two studies relating it to AoA have been conducted.
Anterior Temporal Lobectomy

Anterior temporal lobectomy is often successful in controlling and even eliminating severe seizures in patients with seizures originating in the mesial temporal lobe region. Patients who receive this procedure often show a postsurgery decline in verbal episodic memory and object naming ability with unimpaired intellectual and language functions that do not rely on retrieval of learned information (Bell, Davies, Hermann, & Walters, 2000). It is hypothesized that psycholinguistic variables such as AoA can have an effect on pre- and post-operative performance on picture naming tasks.

I. Influence of Age of Acquisition

Bell et al. (2000) examined the picture naming patterns of 43 patients who received an anterior temporal lobectomy to control their seizures, along with 30 controls that had not undergone a lobectomy. All patients included in the study were shown to have language localized to their left brain hemisphere. They were given the Boston Naming Test (BNT) which is a type of picture naming task consisting of 60 large ink drawings that are arranged in order of difficulty, both before the surgery and then again after. The authors first used a simultaneous multiple regression to show that AoA was the strongest significant predictor of both pre- and post-operative naming performance. Next, they performed logistic regressions for each individual patient which showed a statistically significant change in naming between pre- and post-operative testing sessions. Seventeen patients were included in this analysis, which demonstrated that AoA was once again the only predictor of post-operative
performance in 16 of the 17 individuals who were initially successfully named the same items pre-surgery. The words that were named incorrectly at the post-surgery testing session were later-acquired, whereas those words that were preserved were early-acquired. Thus, AoA is an important predictor of stability of performance. Importantly, the individual analyses gave evidence for an “average” performance profile for patients with anterior temporal lobectomy, even though they had differing sites of seizure focus and slightly different areas of the brain removed which is in contrast to the individual aphasia patient data found by Nickels and Howard (1995), Ellis et al. (1996), and Cuetos et al. (2002), but in accordance with data from patients with semantic dementia and Alzheimer’s disease who showed similar naming profiles.

Based on the data gathered in this study, it is difficult to offer a possible locus of AoA. Analysis of errors would have shed light on whether patients were experiencing phonological or semantic difficulties, but this data was not recorded. Additionally, object familiarity could have been controlled for since it is often correlated with AoA.

II. Clinical Relevance

The knowledge that AoA can predict the likelihood of an anterior temporal lobectomy patient naming a word incorrectly post-surgery after initially being able to name it correctly pre-surgery can help the patient understand how their linguistic skills will change after surgery. In terms of treatment, perhaps later-acquired words could be trained pre-surgery to strengthen their representations in the mental lexicon.
These words could also be trained after surgery as attempt to restore normal naming performance in these individuals to a computer training program similar to that used by Laganaro et al. (2006).

III. Conclusion

AoA was the only psycholinguistic variable that predicted naming performance both at pre- and post-operative testing sessions in patients who had received an anterior temporal lobectomy to control seizures. Additionally, AoA was the sole predictor of post-operative stability of performance for each individual patient. Although these data from Bell et al. (2000) show robust effects of AoA, they cannot suggest a possible locus for AoA. They do, however, demonstrate that AoA could be used to predict how a patient’s naming abilities will change after surgery and suggest the possibility that later-acquired words could be trained in order to reduce the decline in naming ability. Even though this is the only study relating temporal lobectomy to AoA, it is an especially important case because part of the brain was actually lesioned, unlike in the other impairments explored in this study which arose from vascular problems or degeneration of the brain. Also, the fact that lexical variables were analyzed before surgery makes this experiment especially unique. This study provides further evidence for the universality of AoA – it still exerts an effect on language even when the brain is damaged in diverse ways.
**Future Study**

*Other Patient Populations*

Individuals with schizophrenia have been shown to display many language impairments, including deficits in verbal fluency. In a meta-analysis conducted by Henry and Crawford (2005) it was demonstrated that schizophrenic patients are more impaired on semantic fluency than phonemic fluency. It appears that this semantic impairment manifests itself through a lack of organization and logical associations or possibly a reduction in the size of the lexicon (Henry & Crawford, 2005). In this same analysis, performance on the Boston Naming Test (BNT; a picture naming task sensitive to semantic deficits) was impaired, although not to the same degree as semantic fluency. Since schizophrenic patients show a clear semantic deficit, it would be interesting to test for effects of AoA.

In an unpublished study conducted by the Wesleyan Eye Movement and Reading Laboratory in conjunction with the Wesleyan Schizophrenia Neurocognition Assessment and Treatment Laboratory, schizophrenic patients and controls were given a verbal fluency test consisting of the letter categories A, S, and F, and “animals” as the semantic category. The words produced were analyzed for lexical characteristics such as AoA, word frequency, word length, and typicality (a measure of how representative a word is of the given category; only examined in semantic fluency). Although this is a work in progress, it can be hypothesized that an AoA effect would be found in the semantic fluency task. Since schizophrenics tend to have disorganized thoughts and speech, it is possible that they would have more difficulty
recalling later-acquired words since they are thought to hold a more peripheral place in the network.

*Error Analysis*

Error analysis has proved to be an important tool in terms of trying to localize the effects of AoA, especially in aphasia and Alzheimer’s disease (i.e. Nickels & Howard, 1995; Cuetos et al., 2002; Cuetos et al., 2005a). If AoA is found to influence the production of semantic errors, such that when a semantic error was committed, the patient substituted the word for an early-acquired one, it could be hypothesized that the semantic system was damaged and that AoA was facilitating retrieval (although incorrect) at this locus. The most common error types found in the above studies included no-response errors (also called omissions) and semantic errors. Some studies analyzed the direct effects of AoA on error production (e.g. Nickels & Howard, 1995), whereas others reported the types of errors produced and the lexical variables that influenced accuracy separately (e.g. Rodríguez-Ferreiro et al., 2009). In both cases, there seems to be a strong relationship between AoA and the production of no-response and semantic errors, with the exception of Cuetos et al. (2002) who showed an AoA effect on the production of phonological errors. Error production and AoA have only been analyzed in one study of two PPA patients. Given that PPA shares many characters with Alzheimer’s disease such as semantic impairment and degenerative nature, one would expect to find similar AoA effects on error production as well. One of the PPA patients studied (in Hirsh & Funnell, 1995) produced mostly no-response errors, and her naming was predicted by AoA. The other patient showed
only a familiarity effect. Therefore, it will be essential to further explore the relationship between AoA and error production in PPA patients. As stated above, it is difficult to interpret no-response errors, but effects of AoA on semantic errors are somewhat more straight-forward in placing a probable locus for AoA in the semantic system.
Conclusion

Examining the existing literature on the age-of-acquisition effect and patient populations with language impairments has led to conclusions both on how and where AoA acts in the brain, as well as characteristics of the organization (or disorganization) of the mental lexicon that results from brain damage. With regard to a locus or loci for AoA, it seems that the “semantic hub” hypothesis put forth by Steyvers and Tenenbaum (2005), the lexical-semantic competition hypothesis suggested by Brysbaert and Ghyselinck (2006), and the connectionist model proposed by Ellis and Lambon Ralph (2000) are the best candidates. Support for a semantic locus comes from studies that have shown that AoA predicts semantic errors (i.e. Holmes et al., 2006; Nickels & Howard, 1999; Rodríguez-Ferreiro et al., 2009). Additional support for a semantic locus emerged when access to the conceptual and semantic systems was necessary for picture naming tasks (See Figure 3 in Appendix to visualize the amount of support a semantic locus for AoA has gathered). As predicted by Brysbaert and Ghyselinck (2006), larger AoA effects were found when a unique concept had to be selected for, which was the case in picture naming (e.g. Taylor, 1998; Cuetos et al., 2005a; Sartori et al., 2005), and on non-picture naming tasks that required direct access to the semantic system, such as semantic fluency and naming-to-description (i.e. Forbes-Mckay et al., 2005; Sartori et al., 2005). In fact, it was reliably found that AoA effects surpassed frequency effects which, more often than not, failed to reach significance (e.g. Nickels & Howard, 1995; Cuetos et al., 2005a). Overall, it appears that AoA does not occupy a single locus, but instead exerts an influence at multiple levels either through connections between
representations or on multiple representations themselves. Support for Ellis and Lambon Ralph (2000)’s connectionist model was found in studies examining aphasia (Cuetos et al., 2010), dyslexia (Law et al., 2008), and graphemic buffer disorder (Sage & Ellis, 2004).

With regard to the various patient populations examined in this study, it appears that in some populations, an “average patient profile” emerged (i.e. Hirsh & Funnell, 1995; PPA), whereas in others, an average profile did not exist, and instead various sub-populations emerged in the data (i.e. Nickels & Howard, 1995). This difference can be demonstrated by breaking down the group analysis into individual analyses, such that if the group analysis shows a significant effect of AoA which then predicted the performance of only a few individuals, it could be hypothesized that not every patient has an analogous underlying deficit. This point also highlights the importance of conducting individual analyses on patient data since a large amount of variability can exist in a given population. Along the same lines of statistical analysis, it is crucial to carefully choose the correct statistical technique to analyze the data, especially when working with lexical variables that are highly intercorrelated. Thus, simultaneous regression and more advanced modeling techniques have emerged as essential tools in patient data analysis.

Age of acquisition effects have been demonstrated in many patients, ranging from those suffering from aphasia, primary progressive aphasia, Alzheimer’s disease, dyslexia, dysgraphia, and patients who had an anterior temporal lobectomy. AoA also appears to be the most commonly found lexical variable to influence performance on various picture naming and word recognition tasks, often times overshadowing
effects of frequency and familiarity, two variables that are highly correlated with AoA. This speaks to the disorganization of the damaged brain. Whether the damage is vascular, developmental, or degenerative, AoA seems to play an important role, suggesting that there is something unique about learning a word earlier in life and how it influences in the organization of the brain. Through better understanding the deficits of patients and the influence of AoA, better diagnoses can be made, and thus better treatment and rehabilitation plans can be implemented. Cuetos et al. (2005a) and Cuetos et al. (2008) demonstrated that AoA has the potential to predict the level of severity of the cognitive deterioration due to Alzheimer’s disease, as well as the severity of the course of the illness. AoA shows especially great promise in diagnosing Alzheimer’s disease through using a semantic fluency task. Furthermore, Laganaro et al. (2006) found that AoA predicted progress in a computer training program that repeatedly tested aphasic patients on words that they had failed to name at baseline. Further study will shed light on the way in which the brain is organized, the characteristics of brain pathology involved in language deficits, and how to effectively diagnose and treat these impairments.
References


Zevin, J. D. & Seidenberg, M. S. (2002). Age of acquisition effects in word reading and other tasks. *Journal of Memory and Language, 47*, 1-29
Appendix

Figure 3: Proportion of Studies Supporting Each Theory of AoA

Proportion of Studies Supporting Each Locus of AoA

<table>
<thead>
<tr>
<th>Impairment</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aphasia</td>
<td>0.6000</td>
</tr>
<tr>
<td>Alzheimer's Disease</td>
<td>0.9000</td>
</tr>
</tbody>
</table>

Note: Only aphasia and Alzheimer’s disease were included in this graph because those were the only impairment types with enough studies that addressed specific loci of AoA. Also, a given locus was counted only if the experimenters explicitly said which locus their data supported. Therefore, studies conducted before the formation of Ellis and Lambon Ralph (2000)’s connectionist model were not counted even if their data seemed to support this theory. The connectionist model seems to have gained much support in recent years, and will likely continue to do so because it encompasses effects of AoA seen at multiple loci, which was the case in most of the patient populations reviewed here.
<table>
<thead>
<tr>
<th>Study</th>
<th>Language</th>
<th>N</th>
<th>Age (Range or Mean)</th>
<th>Task</th>
<th>No. of items</th>
<th>Statistical Analysis</th>
<th>Significant variables</th>
<th>Non-significant variables</th>
<th>Errors &amp; AoA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feyereisen et al.</td>
<td>French</td>
<td>18 aphasia</td>
<td>25-74 yrs</td>
<td>Picture naming</td>
<td>64</td>
<td>Simultaneous multiple regression</td>
<td>AoA, Fam, Freq</td>
<td>Oper</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>13 controls</td>
<td>20-60 yrs</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Hirsh and Ellis</td>
<td>English</td>
<td>1 (NP)</td>
<td>69 yrs</td>
<td>Spoken &amp; written naming; reading aloud; repetition</td>
<td>100</td>
<td>Multiple linear regression</td>
<td>AoA, L</td>
<td>Freq, Im, Con, Fam</td>
<td></td>
</tr>
<tr>
<td>(1994)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nickels and Howard</td>
<td>English</td>
<td>Study 1: 12</td>
<td>44-76 yrs</td>
<td>Picture naming</td>
<td>208</td>
<td>Simultaneous multiple regression</td>
<td>AoA, Oper, L</td>
<td>Freq, Fam, Im, Con, VC</td>
<td></td>
</tr>
<tr>
<td>(1995)</td>
<td></td>
<td>aphasia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Study 2: 15</td>
<td>28-86 yrs</td>
<td>Picture naming</td>
<td>130</td>
<td>Simultaneous multiple regression (gp); Discriminant analysis (ind)</td>
<td>AoA, L, Im</td>
<td>Freq, Fam, Oper</td>
<td>Semantic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>aphasia</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Ellis et al.</td>
<td>English</td>
<td>6 aphasia</td>
<td>43-72 yrs</td>
<td>Picture naming</td>
<td>139</td>
<td>Simultaneous multiple regression (gp); Logistic regression (ind)</td>
<td>AoA, Im (gp); AoA in 3 (ind)</td>
<td>Fam, Freq, L</td>
<td></td>
</tr>
<tr>
<td>(1996)</td>
<td></td>
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<td></td>
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<tr>
<td>Kay et al.</td>
<td>English</td>
<td>1 (BG)</td>
<td>70 yrs</td>
<td>Picture naming</td>
<td>100</td>
<td>Simultaneous multiple regression</td>
<td>AoA</td>
<td>VC, Im, Con, Ani, Freq, Fam, L, NA, PN</td>
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<tr>
<td>(2001)</td>
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<td>proper name</td>
<td></td>
<td>Picture naming</td>
<td>195</td>
<td>Simultaneous multiple regression</td>
<td>AoA, Fam, NA</td>
<td>VC, Im, Con, Ani, Freq, L, PN</td>
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<tr>
<td></td>
<td></td>
<td>anomia</td>
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<td></td>
<td>Celebrity picture naming</td>
<td>120</td>
<td>Proportion correct</td>
<td>AoA</td>
<td></td>
<td></td>
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<tr>
<td>Cuetos et al.</td>
<td>Spanish</td>
<td>16 aphasic</td>
<td>30-78 yrs</td>
<td>Picture naming</td>
<td>140</td>
<td>Simultaneous multiple regression (gp &amp; ind)</td>
<td>AoA, Freq, Fam, VC (gp); AoA (ind)</td>
<td>Im, Ani, L</td>
<td>Semantic, phonological</td>
</tr>
<tr>
<td>Study</td>
<td>Language</td>
<td>Disorder</td>
<td>Age</td>
<td>Task</td>
<td>Items</td>
<td>Statistical Analysis</td>
<td>Significant Effects</td>
<td>Non-Significant Effects</td>
<td>AoA Effects on Error Production</td>
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<tr>
<td>Cuetos et al. (2005b)</td>
<td>Spanish</td>
<td>6 pure anomia</td>
<td>20-72 yrs</td>
<td>Picture naming</td>
<td>80</td>
<td>Study 1: Semi-factorial design</td>
<td>AoA</td>
<td>Freq</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>6 pure anomia</td>
<td>51-74 yrs</td>
<td>Picture naming</td>
<td>60</td>
<td>Study 2: Factorial design</td>
<td>AoA</td>
<td>Freq</td>
<td></td>
</tr>
<tr>
<td>Laganaro et al. (2006)</td>
<td>French</td>
<td>3 aphasia</td>
<td>30-58 yrs</td>
<td>Picture naming</td>
<td>390</td>
<td>Logistic regression (ind.)</td>
<td>AoA</td>
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<td></td>
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<td>Simultaneous multiple regression (ind)</td>
<td>AoA</td>
<td>IA, Fam, VC, IV, Freq, L, PN, SyllFreq</td>
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<tr>
<td>Kittredge et al. (2008)</td>
<td>English</td>
<td>50 aphasia</td>
<td>22-86 yrs</td>
<td>Picture naming</td>
<td>175</td>
<td>Multinomial logistic regression</td>
<td>AoA, Freq</td>
<td>PD, L, Im, NA</td>
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<tr>
<td>Postman-Caucheteux et al. (2010)</td>
<td>English</td>
<td>3 aphasia</td>
<td>48-68 yrs</td>
<td>Picture naming; event-related fMRI</td>
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<td>Correlation; amplitude modulated regression</td>
<td>AoA</td>
<td>Omissions</td>
<td></td>
</tr>
</tbody>
</table>

Note: Included are the language investigated in the study; the number of participants tested and their disorder; the age of the participants (range or mean); the task used; the number of items; the type of statistical analysis used; significant effects; non-significant effects; AoA effects found on error production, if recorded; AoA = age of acquisition; Freq = word frequency; Fam = familiarity, Im = imageability, VC = visual complexity, L = word length in phonemes, PD = phonological density, NA = name agreement, SyllFreq = syllable frequency, Con = concreteness, IV = image variability, IA = image agreement, PN = phonological neighborhood, Ani = animacy, Oper = operativity

*Amplitude modulated regression was an analysis used to discover if the fMRI data (BOLD response amplitude) varied proportionally with AoA.
Table 2: Studies on Primary Progressive Aphasia and Age of Acquisition

<table>
<thead>
<tr>
<th>Study</th>
<th>Language</th>
<th>N</th>
<th>Age (range or mean)</th>
<th>Task</th>
<th>No. of items</th>
<th>Statistical Analysis</th>
<th>Significant variables</th>
<th>Non-significant variables</th>
<th>Errors &amp; AoA</th>
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</thead>
<tbody>
<tr>
<td>Lambon Ralph et al. (1998)</td>
<td>English</td>
<td>9 PPA 24 controls</td>
<td>NR³</td>
<td>Picture naming</td>
<td>132</td>
<td>Simultaneous linear regression (gp)</td>
<td><em>AoA</em>, Fam, Freq</td>
<td>Cat, Im, NA, L, VC</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 PPA (JL)⁴</td>
<td>NR²</td>
<td>Picture naming</td>
<td>132 (4x)</td>
<td>Logistic regression</td>
<td><em>AoA</em>, Fam, Freq</td>
<td>Cat, Im, NA, L, VC</td>
<td></td>
</tr>
<tr>
<td>Ukita et al. (1999)</td>
<td>Japanese</td>
<td>1 PPA²</td>
<td>59 yrs</td>
<td>Picture naming</td>
<td>100</td>
<td>Multiple Regression</td>
<td><em>AoA</em></td>
<td>Freq, Hist Word</td>
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<tr>
<td>Kremin et al. (2001)</td>
<td>French</td>
<td>8 PPA</td>
<td>65 yrs</td>
<td>Picture naming</td>
<td>100</td>
<td>Multiple Regression</td>
<td><em>AoA</em> (5/8), Freq, NA, VC, Cat⁴</td>
<td>Fam, L</td>
<td></td>
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<tr>
<td>Woollams et al. (2008)</td>
<td>NR²</td>
<td>78 PPA</td>
<td>62.8 yrs</td>
<td>Picture naming</td>
<td>225</td>
<td>Simultaneous multiple regression</td>
<td><em>AoA</em>, Typ, Fam, Freq</td>
<td>Cat</td>
<td></td>
</tr>
</tbody>
</table>

Note: Included are the language investigated in the study; the number of participants tested and their disorder; the age of the participants (range or mean); the task used; the number of items; the type of statistical analysis used; significant effects; non-significant effects; AoA effects found on error production, if recorded; AoA = age of acquisition; Freq = word frequency; Fam = familiarity; Im = imageability; VC = visual complexity; L = word length in phonemes; NA = name agreement; Cat = category (living vs. non-living); Typ = typicality

³This was a longitudinal study conducted over 2 years
⁴This was a longitudinal study conducted over 4 years
²NR = not reported; patient database was used (most patients likely spoke English)
⁴Advantage for non-living items over living items
Table 3: Studies on Alzheimer’s Disease and Age of Acquisition

<table>
<thead>
<tr>
<th>Study</th>
<th>Language</th>
<th>N</th>
<th>Age (range or mean)</th>
<th>Task</th>
<th>No. of items</th>
<th>Statistical analysis</th>
<th>Significant variables</th>
<th>Non-significant variables</th>
<th>Errors &amp; AoA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kremin et al. (2001)</td>
<td>French</td>
<td>8 AD</td>
<td>72 yrs</td>
<td>Picture naming</td>
<td>100 (50 living, 50 non-living)</td>
<td>Multiple regression</td>
<td>AoA (5/8), NA, Fam</td>
<td>L, Freq, VC, Cat</td>
<td></td>
</tr>
<tr>
<td>Silveri et al. (2002)</td>
<td>Italian</td>
<td>39 AD 12 con 20 young con</td>
<td>70.2 yrs 71.3 yrs 22.2 yrs</td>
<td>Picture naming</td>
<td>80 (40 living, 40 non-living)</td>
<td>Multiple regression</td>
<td>AoA, NA, Cat</td>
<td>Freq, Pro, Fam, L</td>
<td></td>
</tr>
<tr>
<td>Forbes McKay et al. (2005)</td>
<td>English</td>
<td>96 AD 40 controls</td>
<td>63-87 yrs 60-80 yrs (con)</td>
<td>Semantic fluency (animals &amp; fruit)</td>
<td>N/A</td>
<td>MANCOVA</td>
<td>AoA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sartori et al. (2005)</td>
<td>Italian</td>
<td>15 AD 37 controls</td>
<td>75.6 yrs 76.49 yrs (con)</td>
<td>Naming-to-description</td>
<td>100</td>
<td>Correlation; Path Analysis</td>
<td>AoA, SR</td>
<td>Freq, Fam, Typ, Dom, Dist</td>
<td></td>
</tr>
<tr>
<td>Cuetos et al. (2005a)</td>
<td>Spanish</td>
<td>10 AD</td>
<td>72 yrs</td>
<td>Picture naming</td>
<td>100</td>
<td>Multiple regression</td>
<td>AoA</td>
<td>Freq, Fam, Im, Lphon, Lsyll</td>
<td>Semantic, no-responsed</td>
</tr>
<tr>
<td>Holmes et al. (2006)</td>
<td>English</td>
<td>22 AD 22 controls</td>
<td>78.5 yrs 78.6 yrs (con)</td>
<td>Picture naming</td>
<td>50 real objects 35 non-objects</td>
<td>ANOVA</td>
<td>AoA</td>
<td>Freq, Fam, NA, Im, Lsyll</td>
<td>Semantic, no-response</td>
</tr>
<tr>
<td>Moreno-Martinez et al. (2008)</td>
<td>Spanish</td>
<td>14 AD 16 controls</td>
<td>71.1 yrs 72.8 yrs (con)</td>
<td>Picture naming</td>
<td>112</td>
<td>Multiple regression</td>
<td>AD: AoA, Freq, Manip, NA Controls: NA</td>
<td>AD: Fam, Pro, VC Controls: AoA, Fam, Pro, Freq, Manip</td>
<td></td>
</tr>
<tr>
<td>Cuetos et al. (2008)</td>
<td>Spanish</td>
<td>2 AD</td>
<td>Case 1: 78 yrs Case 2: 80 yrs</td>
<td>Picture Naming</td>
<td>100</td>
<td>Simultaneous regression</td>
<td>Case 1: AoA, Freq, Fam (stage 1); AoA, Freq (stage 2)</td>
<td>Im, Lsyll, Lphon</td>
<td>Case 1: no-response</td>
</tr>
<tr>
<td>Study</td>
<td>Language</td>
<td>Group (N)</td>
<td>Age (Mean/Range)</td>
<td>Task</td>
<td>Items</td>
<td>Analysis</td>
<td>Effects</td>
<td>Notes</td>
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<td>----------------------------</td>
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</tr>
<tr>
<td>Venneri et al. (2008)</td>
<td>English</td>
<td>25 AD</td>
<td>75.88 yrs (72.12 yrs (con))</td>
<td>Semantic fluency (animals and fruit); MRI scan</td>
<td>N/A</td>
<td>ANOVA (for semantic fluency)</td>
<td></td>
<td>Case 2: AoA, Freq, Fam, VC (stage 1); Fam (stage 2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>25 controls</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Gale et al. (2009)</td>
<td>English</td>
<td>28 AD</td>
<td>83.8 yrs (78 yrs (con))</td>
<td>Picture naming</td>
<td>100</td>
<td>“bootstrap” multiple regression</td>
<td></td>
<td>Case 2: no-response, semantic</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>24 controls</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Rodríguez-Ferreiro et al. (2009)</td>
<td>Spanish</td>
<td>20 AD</td>
<td>82.5 yrs (78.2 yrs (con))</td>
<td>Picture naming</td>
<td>100</td>
<td>Generalized linear mixed-effects modeling</td>
<td></td>
<td>AoA, NA, Freq, VC</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 controls</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Cuetos et al. (2010)</td>
<td>Spanish</td>
<td>22 AD</td>
<td>80.6 yrs (80.7 yrs (con))</td>
<td>Lexical decision</td>
<td>120 real words 180 non-words</td>
<td>ANOVA</td>
<td></td>
<td>Mostly semantic and no-response</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>22 controls</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marques et al. (2010)</td>
<td>Italian</td>
<td>20 AD</td>
<td>AD: 76 yrs Age-matched: 75.7 Young: 22 yrs</td>
<td>Naming-to-description</td>
<td>64 (32 living; 32 nonliving)</td>
<td>Partial correlation</td>
<td></td>
<td>AoA (in all cases), SR, Cat</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 age-matched con 32 young con</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>AD: 76 yrs Age-matched: 75.7 Young: 22 yrs</td>
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</tr>
</tbody>
</table>

Note: Included are the language investigated in the study; the number of participants tested and their disorder; the age of the participants (range or mean); the task used; the number of items; the type of statistical analysis used; significant effects; non-significant effects; AoA effects found on error production, if recorded; AoA = age of acquisition; Freq = word frequency; Fam = familiarity; Im = imageability; VC = visual complexity; L = word length in phonemes; NA = name agreement; Typ = typicality; SR = semantic relevance; Dom = dominance; Dist = distinctiveness; Gram class = grammatical class; Pro = prototypicality; Manip = manipulability; Lsyll = length in syllables

*Patients named more nonliving than living items

**AoA, Freq, Fam, VC were significant when grouped into a “nuissance variables” category for analysis

Third column: Administered on two occasions separated by 2 years

Fourth column: * AoA was the best predictor of change in errors

Fifth column: * AoA only significant in patients

Sixth column: Used to determine brain regions correlated to lexical retrieval

Seventh column: Administered on two occasions separated by 1 year

Eighth column: Only significant for AD patients
Table 4: Studies on Dyslexia and Age of Acquisition

<table>
<thead>
<tr>
<th>Study</th>
<th>Language</th>
<th>N</th>
<th>Age (mean)</th>
<th>Task</th>
<th>No. of items</th>
<th>Statistical Analysis</th>
<th>Significant variables</th>
<th>Non-significant variables</th>
<th>Errors &amp; AoA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baddeley et al. (1988)</td>
<td>English</td>
<td>32 devel dyslexia 32 controls</td>
<td>11 yrs 8-11yrs (con)</td>
<td>Single word reading</td>
<td>172 words 20 non-words</td>
<td>ANOVA</td>
<td>AoA, Im, L</td>
<td>Freq</td>
<td></td>
</tr>
<tr>
<td>Lambon Ralph &amp; Ellis (1997)</td>
<td>English</td>
<td>1 (AB); paralexia</td>
<td>80 yrs</td>
<td>Single word reading</td>
<td>474</td>
<td>Logistic regression</td>
<td>AoA, Im, Freq</td>
<td>Dist, L, Reg</td>
<td></td>
</tr>
<tr>
<td>Gerhand &amp; Barry (2000)</td>
<td>English</td>
<td>1 (LW); deep dyslexic</td>
<td>52 yrs</td>
<td>Single word reading</td>
<td>300</td>
<td>Multinomial logistic regression</td>
<td>AoA, Con, Freq</td>
<td>Freq</td>
<td></td>
</tr>
<tr>
<td>Barry &amp; Gerhand (2003)</td>
<td>English</td>
<td>1 (LW); deep dyslexic</td>
<td>52 yrs</td>
<td>Single word reading</td>
<td>217</td>
<td>Multiple regression</td>
<td>AoA, Freq, Con</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>Barry &amp; Gerhand (2004)</td>
<td>English</td>
<td>1 (LW); deep dyslexic</td>
<td>52 yrs</td>
<td>Single word reading</td>
<td>56</td>
<td>Semifactorial Design: T-tests</td>
<td>AoA, Con</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Picture naming</td>
<td>160</td>
<td>Multiple regression</td>
<td>AoA</td>
<td>Freq, Con, NA, Fam, L</td>
<td></td>
</tr>
<tr>
<td>Toraldo et al. (2006)</td>
<td>Italian</td>
<td>90 aphasic-dyslexic</td>
<td>56.8 yrs</td>
<td>Single word reading</td>
<td>76</td>
<td>ANCOVA</td>
<td>AoA, Freq, L, Con, Gram Class</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Law et al. (2008)</td>
<td>Chinese</td>
<td>1 (FWL); acquired dyslexia 20 controls</td>
<td>50 yrs 48 yrs (con)</td>
<td>Single character reading</td>
<td>260</td>
<td>Simultaneous multiple regression</td>
<td>AoA, PC</td>
<td>Im, Sem Trans, Sem Rad Cons, Sem Rad Comb, VC</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Study</th>
<th>Language</th>
<th>Age of Participants</th>
<th>Task Used</th>
<th>Items</th>
<th>Analysis Type</th>
<th>Significant Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smith-Spark &amp; Moore (2009)</td>
<td>English</td>
<td>18 dyslexia 18 controls</td>
<td>Familiar face naming</td>
<td>50</td>
<td>ANOVA</td>
<td>AoA</td>
</tr>
<tr>
<td></td>
<td>English</td>
<td>20.39 yrs 20.11yrs (con)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chinese</td>
<td>49 yrs 47.9 yrs (con)</td>
<td></td>
<td></td>
<td></td>
<td>Im, Sem Rad Cons, Sem Rad Comb, VC, Freq</td>
</tr>
<tr>
<td>Cushman &amp; Johnson (in press)</td>
<td>English</td>
<td>1 (GJ); pure alexia 6 controls</td>
<td>Eye tracking during sentence reading</td>
<td>27 sentences with 40 target words</td>
<td>Semifactorial design: Independent sample t-tests</td>
<td>AoA</td>
</tr>
<tr>
<td></td>
<td>English</td>
<td>63 yrs 69.2 yrs (con)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Included are the language investigated in the study; the number of participants tested and their disorder; the age of the participants (range or mean); the task used; the number of items; the type of statistical analysis used; significant effects; non-significant effects; effects found on error production, if recorded; AoA = age of acquisition; Freq = word frequency; Fam = familiarity; Im = imageability; VC = visual complexity; L = word length in phonemes; NA = name agreement; SyllFreq = syllable frequency; Con = concreteness; IV = image variability; IA = image agreement; Reg = regularity, Dist = distinctiveness; Gram Class = grammatical class; PC = phonological consistency; Sem Trans = semantic transparency; Sem Rad Cons = semantic radical consistency; Sem Rad Comb = semantic radical combinability

a16 age-matched controls and 16 reading level-matched controls

bNon-words = words that are readily pronounced and have regular spelling to sound correspondence
Table 5: Studies of Dysgraphia and Age of Acquisition

<table>
<thead>
<tr>
<th>Study</th>
<th>Language</th>
<th>N</th>
<th>Age (mean)</th>
<th>Task</th>
<th>No. of items</th>
<th>Statistical analysis</th>
<th>Significant variables</th>
<th>Non-significant variables</th>
<th>Errors &amp; AoA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekes et al. (2003)</td>
<td>English</td>
<td>1 (MK); surface dysgraphia</td>
<td>20 yrs</td>
<td>Spelling to dictation</td>
<td>260</td>
<td>Logistic regression</td>
<td>AoA</td>
<td>Freq, Fam, L</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Spelling, picture naming, repetition</td>
<td>96</td>
<td>ANOVA (semi-factorial)</td>
<td>AoA(^a)</td>
<td>Freq</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Spelling</td>
<td>40</td>
<td>ANOVA (fully factorial)</td>
<td>Pred, AoA for unpredictable words</td>
<td>AoA for predictable words</td>
<td></td>
</tr>
<tr>
<td>Sage and Ellis (2004)</td>
<td>English</td>
<td>1 (BH); graphemic buffer disorder</td>
<td>72 yrs</td>
<td>Spelling to dictation</td>
<td>611</td>
<td>Logistic regression</td>
<td>AoA, ON, Im, L, Freq</td>
<td>Phon to Orth, BiFreq, TriFreq, Germ, OrthoCV</td>
<td></td>
</tr>
</tbody>
</table>

Note: Included are the language investigated in the study; the number of participants tested and their disorder; the age of the participants (range or mean); the task used; the number of items; the type of statistical analysis used; significant effects; non-significant effects; AoA effects found on error production, if recorded; AoA = age of acquisition; Freq = word frequency; Fam = familiarity; L = word length in phonemes; Pred = predictability; ON = orthographic neighbors; Phon to Orth = Phonological to orthographic regularity; BiFreq = bigram frequency; TriFreq = trigram frequency; OrthoCV = orthographic CV structure; Germ = germinate/nongerminate

\(^a\)Only significant for spelling and picture naming
Table 6: Study on Anterior Temporal Lobectomy and Age of Acquisition

<table>
<thead>
<tr>
<th>Study</th>
<th>Language</th>
<th>N</th>
<th>Age (mean)</th>
<th>Task</th>
<th>No. of items</th>
<th>Statistical analysis</th>
<th>Significant variables</th>
<th>Non-significant variables</th>
<th>Errors &amp; AoA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bell et al. (2000)</td>
<td>English</td>
<td>43; left anterior lobectomy 30 controls</td>
<td>33.8 yrs 38.9 yrs (con)</td>
<td>Picture naming</td>
<td>60 items from Boston Naming Test</td>
<td>Simultaneous multiple regression (gp)</td>
<td>Preoperative: AoA, Freq Postoperative: AoA</td>
<td>Cat, L</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Logistic regression (ind)</td>
<td>AoA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Included are the language investigated in the study; the number of participants tested and their disorder; the age of the participants (range or mean); the task used; the number of items; the type of statistical analysis used; significant effects; non-significant effects; AoA effects found on error production, if recorded; AoA = age of acquisition; Freq = word frequency; L = word length in phonemes, Cat = category (living vs. non-living)
Acknowledgements

First and foremost I must thank my advisor, Dr. Barbara Juhasz, for her generous advice, support, and wisdom throughout the entire process. I genuinely thank her for all the time she put into proofreading pages and pages of my work and checking over many other materials. Through working in the Eye Movement and Reading Lab for the past two years under her guidance, I have acquired a countless number of skills that I am sure will aid me in future endeavors. Both in the classroom and in the lab, Barbara has made my experience in psychology and neuroscience at Wesleyan a memorable one.

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