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Age-of-Acquisition Effects in Word and Picture Identification

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Words and pictures with earlier learned labels are processed faster than words and pictures with later learned labels. This age-of-acquisition (AoA) effect has been extensively investigated in many different types of tasks. This article provides a review of these studies including picture naming, word naming, speeded word naming, word pronunciation durations, lexical decisions, eye fixation times, face recognition, and episodic memory tasks. The measurement and validity of AoA ratings is discussed, along with statistical techniques used for exploring AoA's influence. Finally, theories of AoA are outlined, and evidence for and against the various theories is presented.

Keywords: age-of-acquisition, word frequency, word recognition, picture identification

Carroll and White (1973b) first reported that pictures with earlier learned labels were named faster than pictures with later learned labels. Over the past 3 decades, many researchers have studied this contribution of age-of-acquisition (AoA) to the processing of words (De Moor, Ghyselinck, & Brysbaert, 2001). The typical finding is that words that are acquired earlier in childhood are processed quicker or more accurately than words that are acquired later in life (e.g., Carroll & White, 1973b; Gerhand & Barry, 1998; Morrison & Ellis, 1995). This AoA effect is often compared with the word frequency effect, which has been studied much more extensively. Word frequency effects occur when a word that occurs highly frequently in language is processed faster or more accurately than those occurring with a lower frequency. Many models of word processing and reading incorporate word frequency effects to explain some aspect of processing (e.g., M. Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Reichle, Pollatsek, Fisher, & Rayner, 1998). To what extent do word frequency and AoA overlap? Or do they measure different things? Although AoA and frequency may be related, as the review presented in this article makes clear, if anything AoA effects are stronger than frequency effects. Indeed, some AoA researchers (e.g., Morrison & Ellis, 1995) have suggested that previous studies demonstrating frequency effects might have done so because frequency and AoA tend to be highly correlated and earlier frequency studies failed to control for AoA. Although this topic has been debated in the literature, the reality of AoA effects may cause some researchers to rethink their models of word recognition. Do words that are acquired first in a language have a privileged role in the mental lexicon, and if so, why does this occur?

Since the early 1990s, there has been a boom in AoA research that continues to this day. However, there has not been a thorough review of this topic published in more than 20 years (since Gilhooly & Watson, 1981).[1] This current review reports findings from more than 140 studies. The majority of these studies were conducted by researchers outside of the United States. In fact, many prominent language researchers from the United States continue to dismiss the role that AoA plays in lexical processing. This may be because some researchers believe that AoA is simply another measure of word frequency. For example, in a recent large-scale study, Balota, Cortese, Sergent-Marshall, Spieler, and Yap (2004) investigated which variables contribute to word naming and lexical decision performance. Although they included 27 variables in a multiple regression equation, they did not include AoA. In a footnote, they stated that one reason for this was the fact that AoA may be nothing more than a type of frequency effect (as suggested by Zevin & Seidenberg, 2002).

Another possible reason why many researchers ignore AoA effects may be the perceived lack of generality of AoA effects. Many of the early studies of AoA focused on tasks such as picture naming and word naming in a young college-age population. Also, AoA effects were primarily tested with one grammatical category, nouns. The review presented in this article makes clear that AoA effects are observed in many different tasks and different participant groups (including older adults and patients) and can be found with a variety of stimuli, including verbs and nonlinguistic stimuli.

There are legitimate theoretical reasons why researchers should be interested in AoA. Results of AoA studies provide valuable information regarding the relationship between orthography, phonology, and semantics in the mental lexicon. Indeed, as is discussed in more detail toward the end of this article, factor analytic studies suggest that AoA ratings load on more than one factor (Bates, Burani, D'Amico, & Barca, 2001; Rubin, 1980). These factor analytic studies, combined with cognitive modeling efforts (e.g., A. W. Ellis & Lambon Ralph, 2000), suggest that AoA may have more than one locus. Research suggests that one such locus

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[1] After this review was complete, I became aware of an introduction to the special issue of *Visual Cognition* (Johnston & Barry, in press) that provides an overview of many studies of AoA effects. An interested reader is encouraged to read that publication as well.

of AoA effects is the phonological system (so AoA effects may reflect accessing phonology). Of interest, another possible locus may be in the semantic system. Research with connectionist models (also discussed in detail later) suggests that AoA effects are stronger when the relationship between input and output is arbitrary (A. W. Ellis & Lambon Ralph, 2000; Monaghan & Ellis, 2002b; Zevin & Seidenberg, 2002) than when the mapping is consistent. One such arbitrary mapping is between phonology (or orthography) and semantics (Zevin & Seidenberg, 2002). Steyvers and Tenenbaum (2005) recently demonstrated that AoA effects can be incorporated into a model of a semantic network using nondistributed representations. They argued that early acquired words have more semantic connections and, therefore, a more central role in the semantic network. The fact that AoA may be an important factor in the organization of semantic networks makes it clear that it is an important variable theoretically that should be of interest to anyone interested in how words are recognized.

The purpose of this article is to provide a comprehensive review of AoA effects during psycholinguistic tasks. The effects of other psycholinguistic variables (such as word frequency, familiarity, and imageability) are also discussed, but only as far as they relate to AoA. In the remainder of this article, a number of key issues related to AoA effects are discussed in the following sections: (a) the measurement of AoA and other psycholinguistic variables, (b) statistical analyses of AoA, (c) theories of AoA, (d) a summary of major experimental findings, (e) the generality of AoA effects, (f) an evaluation of AoA theories, and (g) conclusions and future directions.

The Measurement of AoA and Other Psycholinguistic Variables

Typically, researchers estimate a word's AoA by having adults rate when they believe they acquired a given word. Gilhooly and Logie (1980a) carried out an extensive AoA rating experiment in which 36 participants rated when they thought that they had learned 1,944 nouns on a 7-point scale (1 = *age 0–2 years*, 7 = *age 13 years and over*). The resulting Gilhooly and Logie (1980a) norms are available on the Medical Research Council Psycholinguistic Database (M. Coltheart, 1981). Many researchers have used this database to gather items for their experiments (e.g., Brown & Watson, 1987; Gerhand & Barry, 1998, 1999a, 1999b; Morrison & Ellis, 1995; Morrison, Ellis, & Quinlan, 1992; Treiman, Mullenix, Bijeljac-Babic, & Richmond-Welty, 1995; Turner, Valentine, & Ellis, 1998). Other researchers have collected their own AoA ratings to use in their studies (e.g., Barry, Morrison, & Ellis, 1997; Feyereisen, Van der Borght, & Seron, 1988; Nagy, Anderson, Schommer, Scott, & Stallman, 1989; Snodgrass & Yuditsky, 1996; Walley & Metsala, 1992).

In addition to Gilhooly and Logie (1980a), published AoA norms exist for English (Bird, Franklin, & Howard, 2001; Carroll & White, 1973a; Fear, 1997; Gilhooly & Hay, 1977; Gilhooly & Logie, 1980b; Masterson & Druks, 1998; Stratton, Jacobus, & Brinley, 1975), as well as Spanish (Cuetos, Ellis, & Alvarez, 1999; see also Piñeiro & Manzano, 2000, for AoA classification based on children's speech), French (Alario & Ferrand, 1999; Bonin, Peereman, Malardier, Meot, & Chalard, 2003), Welsh (Fear, 1997), Italian (Barca, Burani, & Arduino, 2002; Dell'Acqua, Lotto, & Job, 2000), Dutch (Ghyselinck, Custers, & Brysbaert, 2003; Ghyselinck, De Moor, & Brysbaert, 2000), and Icelandic (Pind, Jonsdottir, Gossurardottir, & Jonsson, 2000). There is also a new online source of AoA ratings for pictures of objects and actions for seven languages (Szekely et al., 2004). These published norms are a rich resource to aid researchers in the selection of their stimuli for AoA experiments.

Obviously, most adults do not remember the exact age at which they learned a certain word. AoA ratings are also highly correlated with many other variables such as familiarity, imageability, frequency of usage, and concreteness (see Morris, 1981). These high intercorrelations have raised questions as to the validity of AoA ratings as an independent variable in behavioral studies (Zevin & Seidenberg, 2002). Zevin and Seidenberg (2004) suggested that instead of AoA, a variable called *frequency trajectory* may be a better variable to test what they refer to as *age-limited learning*. The pros and cons of this variable are discussed at the end of this article.

AoA ratings have been found to correlate highly with more objective measures of AoA. For example, Carroll and White (1973b) used indices of children's word frequency counts to provide objective data. The word frequency counts were taken from studies examining the frequency with which different age groups use certain words in reading and writing. They found that their own AoA ratings correlated .85 with these objective measures. Gilhooly and Gilhooly (1980) found a correlation of .93 between their ratings of AoA and the standardized Crichton/Mill Hill vocabulary norms. They also found a correlation of .84 between their AoA ratings and the ability of participants ages 5 to 21 to give acceptable definitions. Other studies (De Moor, Ghyselinck, & Brysbaert, 2000; Jorm, 1991) have also provided evidence for the validity of AoA ratings as a psycholinguistic variable.

One recent attempt to find objective AoA norms was reported by Morrison, Chappell, and Ellis (1997). They had children who ranged from 2 to 10 years of age try to name 297 pictures. If 75% of the children in two successive age groups could accurately name the picture (either on their own or when given the initial phoneme), then the word was given the age rating (in months) of the youngest age group that could name the picture. They found that the objective AoA correlated .747 with AoA ratings given by adults. They concluded that AoA ratings by adults do provide a good method of estimating actual AoA but that objective measures should be used whenever possible. Recently Chalard, Bonin, Meot, Boyer, and Fayol (2003) collected objective AoA norms for the French language, using a procedure very similar to that of Morrison et al. (1997). They found that objective AoA was the best predictor of rated AoA in a stepwise regression analysis.

In addition to AoA, many researchers have also studied the effects of word frequency on picture or word recognition (e.g., Oldfield & Wingfield, 1965; Schilling, Rayner, & Chumbley, 1998). These word frequency effects emerge when a word that occurs with high frequency in the particular language being studied is processed faster, or responded to quicker, as compared with a word that occurs with lower frequency. Frequency is often estimated by using norms that are available on disk or online. These estimates use samples of text or speech to measure how often a given word occurs in the sample. For example, the Kucera and Francis (1967; also Francis & Kucera, 1982) norms are used in many studies examining AoA effects. These norms have been compiled by measuring how often a given word occurs in a sample

of 1 million words. These frequency norms are used to index how often a given person comes in contact with a word in reading or speech. There are also more recent word frequency estimates that are based on larger text corpora such as the CELEX database (Baayen, Piepenbrock, & Gulikers, 1995) and *The Educator's Word Frequency Guide* (WFG; Zeno, Ivens, Hillard, & Duvvuri, 1995). It is important to note that although word frequencies are merely estimates, the frequency effect is very robust and frequency is often manipulated in many studies of word recognition. However, it should also be noted that frequency estimates are usually based on written texts and not on casual speech. This may be one reason that frequency norms have been found to be inaccurate in some cases, especially at the low end of the frequency scale (e.g., Gernsbacher, 1984). I return to a discussion of the various frequency norms at the end of the article.

There is a difficulty with comparing frequency and AoA effects in studies (which is often done). Because AoA and word frequency are not measured on the same scale, it is hard to know whether the ranges of AoA values used in a particular study are comparable to the ranges of frequency used in that study. This should be kept in mind when attempting to compare whether a frequency effect, AoA effect, or both are found in an experiment. However, certain techniques can be used to address this issue. Recently, Lewis, Chadwick, and Ellis (2002) described a way to compare the size of a frequency manipulation with the size of an AoA manipulation in a factorial design. They noted that although the ratio of high- to low-frequency items may be larger than the ratio of early to late AoA items in a study, the variance for the frequency items will also be greater. Thus, they suggested taking the *z* score (a standard score that takes variability into account) for the difference between the high- and low-frequency sets of words and comparing it to the *z* score for the difference between early and late AoA sets of words. This will then illustrate whether the manipulations of frequency and AoA are comparable.

There are many other psycholinguistic variables that have been of interest to AoA researchers in addition to word frequency. Among them are imageability, concreteness, word familiarity, and meaningfulness. Like AoA, these variables are most often measured by having groups of participants rate words on a scale relating to the variable in question. Also like AoA, there are ratings available for these measures on the MRC Psycholinguistic Database (M. Coltheart, 1981).

Statistical Analyses of AoA

AoA effects have been studied using different statistical techniques. These techniques are referred to many times during this review of the literature, so a brief description of them is warranted.

There are two types of multiple regression designs that have been used in the literature; simultaneous multiple regression and stepwise multiple regression. In simultaneous multiple regression, multiple predictors are entered into the regression equation at the same time. Each predictor's unstandardized regression coefficient then represents the change in the dependent variable with a 1-unit increase in the predictor variable, with all other variables held constant. One problem with this type of design is that high intercorrelations between the predictor variables in the equation can cause problems with multicollinearity, resulting in inflated standard errors and difficulty in finding significant effects. As Morris (1981) noted, many of the predictor variables in psycholinguistic research are correlated with each other, making the issue of multicollinearity very pervasive in psycholinguistic multiple regression experiments. This is especially true when predictor variables that are measuring the same construct (such as several different frequency measures) are entered into a simultaneous multiple regression equation. Stepwise multiple regression has other problems associated with it as well as multicollinearity. In stepwise regression, variables are entered into the regression equation in a specific order, either based on their correlation with the dependent variable or based on a priori theoretical assumptions about which variables should be entered first. Although stepwise regressions are an appropriate and powerful technique for obtaining the best regression equation for prediction, the probability values associated with each predictor variable are not correct when the predictors entered into the equation are selected from a larger pool (Myers & Well, 1995). Morris also noted that the order in which variables are entered into a stepwise regression can change the interpretations of which variables are important. For example, if AoA and frequency are both correlated with the dependent variable and each other, the inclusion of one of these variables as the first variable in the stepwise regression may make the other variable become not significant in the equation (because of their shared variability).

A third type of statistical technique is factor analysis. In factor analysis, intercorrelations between variables are examined as a measure of association. Factor analytic techniques attempt to explain this pattern of intercorrelations by positing underlying factors that account for them (Kim & Mueller, 1978). Thus, many psycholinguistic variables can be pared down to a handful of factors. Factor analytic techniques can offer insight into the nature of the AoA effect by showing the factor(s) with which it is associated (Bates et al., 2001; Rubin, 1980).

As mentioned earlier, Morris (1981) criticized the use of multiple regression designs because of the high intercorrelations between variables. Instead of using multiple regression, he used what is referred to here as a *partial factorial design*. Other researchers have also used this type of factorial design to investigate AoA and word frequency effects. In this type of design, AoA is manipulated while word frequency and other variables are controlled. In a separate experiment, word frequency can be manipulated while AoA and other variables are controlled (e.g., Barry, Hirsh, Johnston, & Williams, 2001; Morrison & Ellis, 1995; Turner et al., 1998). However, just as with the regression techniques, there are difficulties with this technique. First, this design makes it impossible to assess whether there are interactions between AoA and other variables, as only one variable is manipulated at a time. Also, picking items for the factorial design may be subject to experimenter bias (Forster, 2000). Finally, it is nearly impossible (Cutler, 1981) to control for all of the potentially confounded variables—such as imageability, length, frequency, AoA, concreteness, initial phoneme (in naming studies), meaningfulness, morphological complexity, and so forth—in factorial designs.

A few researchers have used a fully factorial design to study AoA and word frequency (e.g., Gerhand & Barry, 1998, 1999a, 1999b). Lewis (1999a; Lewis, Gerhand, & Ellis, 2001) argued against using factorial designs to study the effects of AoA and word frequency. He suggested that factorial designs ignore the nonlinear effects these variables have on behavioral measures. In

addition, the difficulties associated with the partial factorial design (inability to control for all potentially confounding variables and experimenter bias in choosing stimuli for the cells) are also associated with fully factorial designs.

The preceding discussion highlights that there is no perfect statistical technique for studying the effects of psycholinguistic variables (see also Lewis, in press, for a discussion of problems associated with statistical analyses of psycholinguistic phenomena). Therefore, the best course of action is to compare studies that have used varying techniques to find converging results.

Theories of AoA Effects

Multiple theories have been proposed to explain AoA effects. They are (a) the bilateral representation hypothesis, (b) the phonological completeness hypothesis, (c) the cumulative frequency hypothesis, (d) the semantic locus hypothesis, (e) the neural plasticity hypothesis, and (f) the lexical–semantic competition hypothesis. In the following sections, each of the hypotheses are introduced. Whereas the first hypothesis can be discarded rather easily, the other five are viable accounts of the locus of AoA effects. After the review of experimental findings, the five remaining theories are revisited and evidence for and against them is discussed.

Bilateral Representation Hypothesis

One early hypothesis as to the locus of AoA effects was discussed (but subsequently dismissed) by H. D. Ellis and Young (1977). They hypothesized that AoA effects might be due to the fact that early acquired words are represented in both hemispheres of the brain, whereas later acquired words are only represented in the left hemisphere. H. D. Ellis and Shepherd (1974) found that concrete words were significantly better recognized when presented to the left visual field (and hence the right hemisphere), whereas there was no difference between abstract and concrete words presented to the right visual field (and hence the left hemisphere). As AoA is known to be correlated with concreteness, AoA was suggested as a possible cause of this effect. However, the data did not support this theory. Both H. D. Ellis and Young and Boles, Rogers, and Wymer (1982) have failed to find any interaction between visual field and AoA. Thus, this hypothesis can be rejected.

Phonological Completeness Hypothesis

The phonological completeness hypothesis has been widely mentioned in the literature. According to Brown and Watson (1987), earlier learned words are easier to pronounce than words that are acquired later. When Brown and Watson first proposed this theory, AoA effects had been reliably observed only in tasks that required overt verbal responses. According to this theory, AoA effects reside in the speech output lexicon and are observed when participants need to access the phonology for a word.

Proponents of the phonological completeness hypothesis do not believe that initiating the articulation of early acquired words occurs any faster than that of late acquired words because there is no evidence of an AoA effect in delayed naming (e.g., Gerhand & Barry, 1998; Morrison & Ellis, 1995). According to the phonological completeness hypothesis, the phonology of early acquired words is stored in a complete manner in the speech output lexicon, whereas late acquired words' phonologies are segmented and have to be generated each time the word is spoken. Therefore, it takes longer to generate the phonology of a late acquired word than merely to access the full phonology of an early acquired word.

There is some evidence that very young children do treat words as unanalyzed wholes as opposed to segments (Walley, 1993). However, developmental researchers who have proposed this also believe that there is a period when children need to reorganize their lexicons into segmentally based representations in order to have a more efficient system of storage (Walley, 1993). Morrison and Ellis (2000) argued that all that is needed to bring together the AoA and developmental word acquisition literature is to suggest that earlier learned words retain a somewhat more holistic phonological representation than late acquired words.

Cumulative Frequency Hypothesis

Another reason that AoA effects might be observed in word processing tasks is because early acquired words have simply been encountered more times during a participant's lifetime than late acquired words. This theory was first proposed in the beginning of AoA research (Carroll & White, 1973b). For example, when Brown and Watson (1987) first described the phonological completeness hypothesis, they also discussed what they termed *total life span frequency*. According to this view, one could take the word residence time (the amount of time that a word has been in memory) of a particular item (measured as *Participant Age – AoA*) and multiply this by the frequency of the item to get a measure of the total life span frequency. Gilhooly (1984) also investigated the idea of cumulative frequency but found AoA to be a better predictor of word naming time than word residence in participants ages 20 to 58.

Recently, there has been a revived interest in this hypothesis, starting with Lewis (1999a). He called this theory the *cumulative frequency hypothesis*. Lewis et al. (2001) used the formula $ln(Rt) = -A\ ln(freq) - A\ ln(Age - AoA) + ln(k)$ (where k and A are constants) to reevaluate the cumulative frequency hypothesis in a multiple regression framework. The cumulative frequency hypothesis is an instance-based hypothesis, which tests whether the number of encounters a participant has with a particular word predicts the time it will take for him or her to process the word. The important factor here is not AoA itself, but the number of times that the word had been encountered (*Age – AoA*). Also, because the log of the product of word residence time and frequency is equal to the log of the sum of those two factors, although the aforementioned equation is presented as an additive model, it actually implies a multiplicative relationship between word residence time and word frequency. This multiplicative relationship between word residence time and word frequency is what defines this cumulative frequency hypothesis.

Zevin and Seidenberg (2002) also suggested that AoA effects in the literature may be due to cumulative frequency. They examined the stimuli from factorial studies of AoA and word frequency and noted that whereas the early and late stimuli were matched for Kucera and Francis (1967) frequencies, most of them differed on another frequency corpus, the WFG (Zeno et al., 1995). Zevin and Seidenberg (2002) noted that the WFG provides frequency information for each word at differing grade levels, based on the

reading level of the books that are sampled in this corpus; therefore, the sum of the frequency at different grade levels represents a measure of cumulative frequency. Zevin and Seidenberg (2002) reanalyzed data from three large studies of naming and lexical decision. When other factors were controlled, they found that AoA did not account for any unique variance, whereas the sum for all grade levels in the WFG did. Zevin and Seidenberg (2002) suggested that the WFG estimates index a word's cumulative frequency and, once this is controlled, there is no true effect of AoA.

Semantic Locus Hypothesis

Another hypothesis localizes the AoA effect as a semantic effect: The AoA effect may reside in the accessing of meaning in the lexicon. Brysbaert, Van Wijnendaele, and De Deyne (2000) made reference to Van Loon-Vervoon (1989), who argued that order of acquisition may be the most important factor in that later learned concepts may be built upon earlier learned concepts. Gilhooly and Gilhooly (1979) previously mentioned a similar idea. They argued that because late acquired words are often defined in terms of earlier learned words, the lexical entries for earlier acquired words may be implicitly aroused whenever a late acquired word is encountered, thereby lowering the thresholds of the earlier acquired words.

Steyvers and Tenenbaum (2005) recently incorporated the AoA effect into a simulation of a growing semantic network. They demonstrated that there is a relationship between when a new semantic node enters the network and the number of connections that the node will ultimately have. Thus, early acquired words have more connections in the semantic system than late acquired words. They also suggested that the search involved in lexical retrieval may be biased toward accessing the more highly connected (and thus the more early acquired) nodes first. Thus, Steyvers and Tenenbaum showed that AoA effects could be interpreted in light of the richness of semantic connections that early acquired words have in the mental lexicon. This is especially interesting given that the network created by Steyvers and Tenenbaum was not originally created to account for AoA effects.

Network Plasticity Hypothesis

A. W. Ellis and Lambon Ralph (2000) described a locus for the AoA effect based on simulations from their connectionist model. They observed that when patterns are entered into training early, the network structures itself, through larger weight changes, into a certain configuration. When later learned patterns are entered, the network has lost some of its plasticity. Even if the frequency of the late learned pattern is greater, it is difficult for the network to overcome this loss in plasticity (see also Smith, Cottrell, & Anderson, 2001). This hypothesis is interesting because it suggests that effects of AoA are a property that emerges out of a learning system. Therefore, AoA could affect multiple stages during word recognition.

Recent simulations have further clarified the predictions of the network plasticity hypothesis. Monaghan and Ellis (2002b) trained a network with 100 early patterns and 100 late patterns. Both consisted of 80 consistent input-to-output mappings and 20 inconsistent input-to-output mappings. Some of these patterns were trained with a high frequency in the network, whereas others were trained with a low frequency. They found significant effects of AoA, frequency, and consistency, as well as significant interactions in the network. They concluded that AoA effects should be larger when the mapping from input to output is arbitrary. This supports a conclusion also reached by Zevin and Seidenberg (2002) with simulations from their connectionist model. Zevin and Seidenberg (2002) concluded that when the mapping from input to output is arbitrary (as in the mapping from orthography to semantics), a true AoA effect may be observed. However, when the mapping is relatively consistent (as in naming most English words), apparent AoA effects are merely cumulative frequency effects. This idea is referred to here as the *mapping hypothesis*.

Lexical–Semantic Competition Hypothesis

This hypothesis is fairly new and stems from an observation made by Brysbaert and Ghyselinck (in press). They noted that in experimental tasks such as word naming and lexical decision, the size of the frequency effect and AoA effect are highly correlated and roughly equivalent. This is despite the fact that AoA and frequency were orthogonally manipulated, and the frequency manipulation is often stronger than the AoA manipulation. They referred to this as a *frequency-related AoA effect* and attributed it to the fact that both AoA and frequency effects stem from the same learning process. However, they also noted that in picture naming (and word-associate generation; Brysbaert, Van Wijnendaele, & De Deyne, 2000), the size of the AoA effect is often much larger than the size of the frequency effect. They referred to this as the *frequency-independent AoA effect*. Brysbaert and Ghyselinck (in press) suggested that this frequency-independent AoA effect may result from competition in the conceptual system (when a unique concept must be selected—which is the case in picture naming). This hypothesis would thus also localize AoA as a semantic variable.

Brysbaert and Ghyselinck (in press) also suggested another source for the frequency-independent AoA effect related to Levelt, Roelofs, and Meyer's (1999) word production model. Briefly, Levelt et al.'s model consists of three levels: a conceptual level, a lemma level, and a word form level. In this model, the lemma level contains grammatical information about a word (such as tense) but does not contain phonological information. Once a correct lemma for a given concept is selected, activation spreads from the lemma level to the word's phonological form (the third level in the model). Levelt et al. originally ascribed both word frequency and AoA effects in picture naming to the same level—accessing of the phonological word form. However, Brysbaert and Ghyselinck (in press) suggested that the frequency-independent AoA effect could be related to the competition that arises in the lemma level when the correct lemma for a certain concept must be selected. This theory was referred to as the *lexical–semantic competition hypothesis* by Belke, Brysbaert, Meyer, and Ghyselinck (2005).

Summary of Major Findings

In this section major findings in the literature are outlined according to the task that was used. The review is organized by task because the five theories of AoA effects make different predictions regarding the presence and/or magnitude of AoA effects observed in certain tasks. These predictions are discussed

generally here, and then are discussed in more detail when the theories are evaluated toward the end of the article.

The phonological completeness hypothesis in its strongest form predicts that AoA effects should be observed only in tasks requiring a verbal output. Weaker forms of hypotheses for a phonological locus of AoA may predict AoA effects in any task benefiting from access to stored phonological representations (e.g., Gerhand & Barry, 1999b). The cumulative frequency hypothesis predicts AoA effects should be found in every task in which a frequency effect is usually found. However, an AoA effect should not be observed in these tasks when cumulative frequency is controlled. The semantic locus hypothesis predicts that an effect of AoA should be observed in any task that requires access to semantics. This prediction can be taken further to suggest that the AoA effect should be larger in tasks that rely more on access to semantics. For example, the recent study by Balota et al. (2004) suggested that semantic variables contribute to both the naming task and the lexical decision task but that the effect is larger for the lexical decision task. According to the lexical–semantic competition hypothesis, AoA effects should also be observed in any task where a frequency effect is observed. However, this AoA effect should be of the same magnitude as the frequency effect in all tasks that do not require selection of a unique lemma. Finally, the network plasticity hypothesis predicts AoA effects in all tasks as well, but these effects should be larger when the mapping from input to output is arbitrary.

Picture Naming

This section summarizes the results from the published picture naming studies. Results from several of the more recent picture naming experiments using a regression design as well as a factorial design are presented in Tables 1 and 2, respectively.

Each of the five AoA theories mentioned in the previous section predicts an effect of AoA in picture naming. Thus, if AoA effects are not observed, this would be difficult for any of the theories to account for. However, there does not appear to be one published study investigating AoA effects in picture naming that does not find a significant effect of AoA. The results from the picture naming data are especially important for the lexical–semantic competition hypothesis. One important principle of this hypothesis is that there exists both a frequency-related and a frequency-independent AoA effect (Belke et al., 2005; Brysbaert & Ghyselinck, in press). This frequency-independent AoA effect should be observed in picture naming tasks, resulting in a larger effect of AoA compared with word frequency. The majority of picture naming studies have used a multiple regression design. It is difficult to compare the sizes of AoA and frequency effects in multiple regression because unstandardized regression coefficients (which do not take the differing variability of the two variables into account) are often reported. However, it is possible to compare the significance of the coefficients for AoA compared with frequency. Therefore, in the summary that follows, experiments are classified by whether both AoA and frequency effects are observed or whether just AoA effects (without frequency effects) are observed.

In many English picture naming studies, significant AoA effects are observed without a corresponding frequency effect. In the first major study examining AoA, Carroll and White (1973b) found that whereas AoA was a significant predictor of the time it took to name pictures, there was no independent effect of word frequency. Similarly, Gilhooly and Gilhooly (1979) found that only codability (a measure of the degree to which people agree on the name of a

Table 1
Results From Recent Picture Naming Experiments That Used a Regression Design

Study	Language	*N*	No. of items	AoA	Frequency	Interaction	Significant variables	Nonsignificant variables
Morrison et al. (1992)	English	20	48	Significant	*ns*		L	Im, P
Vitkovitch and Tyrrell (1995)	English	16	40	Significant	*ns*		NA	VC
Snodgrass and Yuditsky (1996)—Experiment 1	English	78	250	Significant	Significant		NA, Fam	IA, L
Barry et al. (1997)	English	26	195	Significant[a]	Significant	Significant	NA, IA[a]	VC, Fam, L, Im
A. W. Ellis and Morrison (1998)	English	30	235	Significant	Significant		VC, NA	L, CF,[b] Im[b]
Cuetos et al. (1999)	Spanish	64	140	Significant	Significant		L, OF, NA, IA	VC
Kremin et al. (2000)	French	56	140	Significant	*ns*		NA	VC, L
Dell'Acqua et al. (2000)	Italian	84	266	Significant[c]	*ns*		T, CA, H	L, Fam, NA
Bonin et al. (2002)	French	36	203	Significant	*ns*	*ns*	NA, IA, IV	Fam, VC, L
Laws et al. (2002)[d]	English	20	120	Significant	*ns*		EO, L	Fam, CO, VC
Pind and Tryggvadottir (2002)	Icelandic	23	175	Significant	*ns*		NA, Fam	IA, L
Morrison et al. (2003)[e]	English	44	110	Significant	*ns*		H	Fam, VC, IA, L, IPM
Morrison et al. (2003)[f]	English	30	110	Significant	Significant		H, VC	Fam, IA, L, IPM

Note. Included are the language investigated in the study; the number of participants and items contributing to the analyses; whether a significant age-of-acquisition (AoA) effect, frequency effect, and interaction were found; other variables found to be significant; and other nonsignificant variables included in the equation. Significant = significant at $p < .05$; L = a measure of word length; Im = imageability; P = prototypicality; NA = name agreement; VC = visual complexity; Fam = familiarity; IA = image agreement; CF = concept familiarity; OF = object familiarity; T = typicality; CA = concept agreement; H = a specific measure of name agreement; IV = image variability; EO = Euclidean overlap; CO = contour overlap; IPM = an initial phoneme measure.

[a] AoA and IA were significant using a one-tailed test. [b] Im and CF were significant only using the Lorch and Myers (1990) procedure. [c] AoA was significant only when CA was left out of the equation. [d] Results reported are from the 0% masking condition in Laws et al. (2002). [e] Results reported are for the younger adults in Morrison et al. (2003). [f] Results reported are for the older adults in Morrison et al. (2003).

Table 2
Results From Recent Picture Naming Experiments That Used a Factorial Design

Study	Type	Language	Design	*N*	No. of items	AoA	Frequency	Interaction	Variables controlled
A. W. Ellis and Morrison (1998)	I	English	Partial	20	50	176*			L, Im, VC, Freq, NA
Barry et al. (2001)[a]	I	English	Partial	24/24	24/24	92*	−23[b]		L, OF, NA, VC, IA
Bonin, Fayol, and Chalard (2001)	I	French	Partial	30/30	36/34	147*	10		L, PGC, NA, IA, VC, BF, CF, IV
Morrison et al. (2002)[c]	I	English	Partial	35	50	212*			L, Im, VC, Freq, NA
Morrison et al. (2002)[d]	I	English	Partial	32	50	150*			L, Im, VC, Freq, NA
Morrison et al. (2002)[e]	I	English	Partial	29	50	167*			L, Im, VC, Freq, NA
Meschyan and Hernandez (2002)[f]	I	English	Full	30	80	115*	31	No	L, Im, VC, NA
Holmes and Ellis (in press)[g]	I	English	Partial	21	50	122*			L, Im, VC, Freq, CF, NA
Holmes and Ellis (in press)[h]	I	English	Partial	25	84	86*			L, VC, Freq, NA
Holmes and Ellis (in press)[i]	I	English	Partial	25	84	41[b]			L, VC, Freq, NA
Barry et al. (in press)[j]	I	English	Partial	19	24	74*			L, OF, NA, VC, Freq, IA
Catling and Johnston (in press)[k]	I	English	Partial	20	56	123*			L, OF, NA, VC, Freq, IA
A. W. Ellis and Morrison (1998)	D	English	Partial	20	50	−6			L, Im, VC, Freq, NA
Barry et al. (2001)	D	English	Partial	24/24	48/48	−1	−5		L, OF, NA, IA, VC
Holmes and Ellis (in press)[i]	D	English	Partial	25	84	−8			L, VC, Freq, NA

Note. Included are the type of picture naming study; the language investigated in the study; the type of factorial design used; the number of participants and items contributing to the analyses; the magnitude of the age-of-acquisition (AoA) effect and frequency effect (in milliseconds) and whether these effects, as well as an interaction, were significant; and variables that were controlled (either experimentally or statistically). For partial factorial designs, the number of participants and items for both the AoA-manipulated lists and frequency-manipulated lists are presented. I = immediate picture naming; L = a measure of word length; Im = imageability; VC = visual complexity; Freq = a measure of frequency; NA = name agreement; OF = object familiarity; IA = image agreement; PGC = phoneme-to-grapheme consistency; BF = bigram frequency; CF = concept familiarity; IV = image variability; D = delayed picture naming.
[a] Results reported are from Stage 1 of Barry et al. (2001). [b] Effect was significant by participants but not by items. [c] Results reported are from the young adults in Morrison et al. (2002). [d] Results reported are from the 60- to 69-year-old group in Morrison et al. (2002). [e] Results reported are from the age 80+ group in Morrison et al. (2002). [f] Results reported are from the 0-ms delay from Experiment 1 in Meschyan and Hernandez (2002). [g] Results reported are from Experiment 1 of Holmes and Ellis (in press). [h] Results reported are from Experiment 5 of Holmes and Ellis (in press) where typicality was also manipulated. [i] Results reported are from Experiment 6 of Holmes and Ellis (in press) where typicality was also manipulated. [j] Results reported are from Stage 1 of Barry et al. (in press). [k] Catling and Johnston (in press) is considered a partial factorial design because frequency was not manipulated. However, AoA was crossed with object type (natural or man-made) in this experiment.
* $p < .05$.

picture) and AoA significantly predicted picture naming latency. Frequency and familiarity were not significant predictors in this experiment. In an influential study, Morrison et al. (1992) reanalyzed data from a study by Oldfield and Wingfield (1965) in which a frequency effect was obtained but AoA was not controlled. The reanalysis included AoA and word frequency along with word length. AoA was the only significant predictor of picture naming speed in this reanalysis. Morrison et al. concluded that the frequency effect that Oldfield and Wingfield found was merely an artifact due to its confound with AoA. Morrison et al. (1992) also replicated these results in a new study.

As indicated in Table 1, the finding of an AoA effect without a corresponding frequency effect in multiple regression studies was also observed in English by Vitkovitch and Tyrrell (1995), as well as Laws, Leeson, and Gale (2002), and with the younger adult participant group in a study conducted by Morrison, Hirsh, and Duggan (2003). In addition, a pattern of AoA effects in multiple regression without a frequency effect was observed in other languages such as Italian (Dell'Acqua et al., 2000), Icelandic (Pind & Tryggvadottir, 2002), and French (Bonin, Chalard, Méot, & Fayol, 2002; Kremin, Hamerel, Dordain, De Wilde, & Perrier, 2000). Recently, Chalard et al. (2003) confirmed these results of Bonin et al. (2002) in French using an objective AoA measure as opposed to an AoA rating. As indicated in Table 2, using a partial factorial design, Bonin, Fayol, and Chalard (2001) also found a significant effect of AoA on picture naming latency in French while frequency and other variables were controlled but no effect of frequency on picture naming latency when AoA and other variables were controlled.

Barry et al. (2001) explored both AoA and repetition priming effects on English picture naming using a partial factorial design. Results from the first stage of their experiment are reported in Table 2, where participants were asked to name pictures that varied in AoA (both rated and objective) but were controlled on several frequency measures (both written and spoken) in addition to other variables. A significant effect of AoA was observed (this effect was subsequently replicated using the same stimuli for both older and younger adults by Barry, Johnston, & Wood, in press). In a second experiment, lists of words were manipulated on several measures of frequency (both written and spoken) and matched on AoA (along with other variables). They found no frequency effect in this experiment.

Although the results from these studies suggest that AoA affects picture naming whereas frequency does not, there are also studies that have found effects of both AoA and word frequency. For example, Lachman (1973) reported effects of both frequency and AoA on picture naming latencies, a result subsequently confirmed by Lachman, Shaffer, and Hennrikus (1974). Table 1 also shows that both AoA and word frequency effects were observed by Snodgrass and Yuditsky (1996) and the older adult group of

Morrison et al. (2003). In addition, similar results were observed in Spanish by Cuetos et al. (1999).

Barry et al. (1997) also examined frequency and AoA effects in picture naming. However, they included spoken frequency (as opposed to many previous studies that used written frequency or rated frequency). They also included an interaction term in the simultaneous multiple regression equation that consisted of AoA × Spoken Frequency, along with other predictors. They found that the significant predictors of picture naming latency were spoken frequency, name agreement, and the interaction term (AoA × Spoken Frequency). Using a one-tailed test, AoA was also significant. The significant interaction indicated an effect of frequency for late acquired names, but not for early acquired names. They concluded that the reason frequency effects were not found in the previous studies was because of the frequency indices used. This idea was supported by A. W. Ellis and Morrison (1998), who reevaluated the influence of AoA on picture naming by using objective AoA norms from Morrison et al. (1997). They used a simultaneous multiple regression design in which pictures varied on a number of factors and found that although objective AoA still predicted average picture naming latency, spoken word frequency was also a significant predictor.

Further support for a joint contribution of AoA and word frequency to picture naming comes from designs in which AoA and frequency were manipulated orthogonally. For example, Meschyan and Hernandez (2002) manipulated AoA and rated frequency along with the delay between when the picture appeared and when the cue to name it appeared. They found significant effects of both AoA and frequency. AoA and frequency also interacted across delays, such that the word frequency effect was larger for late acquired words as the delay increased. Lambon Ralph and Ehsan (in press) orthogonally manipulated both objective AoA and word frequency in a picture naming experiment. They obtained both AoA and frequency effects, as well as a marginal interaction between the two variables.

The review of the picture naming studies indicates that AoA is always a significant predictor of picture naming latency. Frequency, on the other hand, is often not significant. One possible reason that frequency effects may not be observed could be problems of multicollinearity as indexed by high intercorrelations between variables included in the regression studies. These high intercorrelations among predictors can be observed in the correlation tables of Gilhooly and Gilhooly (1979), Morrison et al. (1992), and Pind and Tryggvadottir (2002), among others. Also, as Barry et al. (1997) noted, part of the difference in whether frequency effects are observed in picture naming may have to do with the frequency index used. Not all frequency indices are equal as discussed at the end of this article (see also Balota et al., 2004; Zevin & Seidenberg, 2002).

Some of the studies reported in Table 2 that have used a factorial design to investigate AoA effects in picture naming did not investigate word frequency effects (e.g., A. W. Ellis & Morrison, 1998; Holmes & Ellis, in press; Morrison, Hirsh, Chappell, & Ellis, 2002). It is obvious that the AoA effect in all studies reported in Table 2 is rather large. In fact, the average effect from the 10 immediate picture naming studies is 125 ms. As is discussed later, this AoA effect is substantially larger than that observed in lexical decision or word naming (supporting both the semantic hypothesis and the network plasticity hypothesis). Also, this effect is much larger than any observed frequency effect reported in Table 2, supporting the notion of a frequency-independent AoA effect as suggested by the lexical–semantic competition hypothesis (Belke et al., 2005).

Written Picture Naming

All of the studies mentioned earlier used naming latency to a pictured stimulus as the dependent measure. However, there is also work by Bonin and colleagues (Bonin et al., 2002; Bonin, Fayol, & Chalard, 2001; Bonin & Meot, 2002) that investigated AoA effects on the latency to write the name of pictures. The findings from this variant of the picture naming task are in total agreement with the results of the verbal picture naming task as far as AoA effects are concerned. Using the same items as mentioned earlier for verbal naming, Bonin, Fayol, and Chalard (2001) found a significant effect of AoA when frequency was controlled, but no effect of frequency when AoA was controlled. Bonin et al. (2002) also found the same predictors to be significant in written picture naming as in spoken picture naming using a simultaneous multiple regression technique.

The results from these written picture naming studies may appear to be at odds with a strong interpretation of the phonological completeness hypothesis, but they can be incorporated into a weaker version (assuming the written picture naming requires access to a stored phonological representation). It can also be easily incorporated in the semantic hypothesis, cumulative frequency hypothesis, network plasticity hypothesis, or the lexical–semantic selection hypothesis (because lemmas would presumably be accessed prior to the orthographic word form).

Object Recognition

In the previous section, studies showing large effects of AoA on picture naming were reviewed. However, as Levelt (2002) discussed, studies that use picture naming as a way to localize AoA and frequency effects have not controlled for object recognition speed. It is therefore difficult to assess whether those results show that AoA is affecting the time it takes to name a picture, the time it takes to recognize a picture, or both. Levelt criticized two AoA studies (Barry et al., 2001; Bonin et al., 2002) for not applying appropriate object recognition speed controls, but the majority of the studies reported earlier are subject to the same criticism. It should be noted that this criticism can also be applied to studies exploring only frequency effects in picture naming as well (e.g., Oldfield & Wingfield, 1965).

AoA effects have been tested in some object recognition experiments. Using a simultaneous multiple regression, Morrison et al. (1992) failed to find a significant effect of AoA on the time it took participants to correctly identify pictures as either artificially constructed or naturally occurring (category membership and prototypicality were the only significant predictors). However, this study has been criticized for many reasons, including its data analysis (Brysbaert, Van Wijnendaele, & De Deyne, 2000) as well as the small number of items used (Holmes & Ellis, in press).

Recent studies have found evidence of AoA effects on object categorization speeds. For example, Vitkovitch and Tyrrell (1995) found AoA to be a significant predictor of the latency to decide whether a line drawing represented an object or a nonobject.

Table 3
Results From Recent Word Naming Experiments That Used a Regression Design

Study	Type	Language	*N*	No. of items	AoA	Frequency	Significant variables	Nonsignificant variables
Brown and Watson (1987)	I	English	28	416	Significant	*ns*		Fam,† L,† IPM,† Im, BF, C, A
Yamazaki et al. (1997)	I	Japanese	26	147	Significant	*ns*	AoAW, Fam	Cfreq,† AP, L, VC
Morrison and Ellis (2000)	I	English	27	220	Significant	Significant	IPM, L, N	Fam, Im, IPM
Morrison et al. (2003)[a]	I	English	30	267	Significant	*ns*	IPM	Fam, Im, L†
Morrison et al. (2003)[b]	I	English	30	267	Significant	*ns*	IPM	Fam, Im, L, IPM

Note. Included are the type of naming experiment; the language investigated in the study; the number of participants and items contributing to the analyses; whether a significant age-of-acquisition (AoA) effect, frequency effect, and interaction were found; other variables found to be significant; and other nonsignificant variables included in the equation. I = immediate naming; Significant = significant at $p < .05$; Fam = familiarity; L = a measure of word length; IPM = an initial phoneme measure; Im = imageability; BF = bigram frequency; C = concreteness; A = ambiguity; AoAW = written AoA; Cfreq = character frequency; AP = number of alternative pronunciations; VC = visual complexity; N = a measure of neighborhood size.
[a] Results reported are from the young adult group in Morrison et al. (2003). [b] Results reported are from the older adult group in Morrison et al. (2003).
† $.05 < p < .10$.

Moore, Smith-Spark, and Valentine (2004) investigated the same topic using a partial factorial design. They found a significant 24-ms effect of AoA on the latency to make an object–nonobject decision with word frequency controlled as well as a significant (by participants) 23-ms effect of word frequency when AoA was controlled. Holmes and Ellis (in press) likewise found a 42-ms significant effect of AoA in the same type of task with frequency controlled when realistic nonobjects were used and a 35-ms significant effect with less realistic nonobjects. In a third experiment (in which category typicality of the objects was varied as well), the AoA effect on object decision speeds was larger when participants did not perform articulatory suppression exercises (58 ms) than when they did (28 ms), although the effect was still significant in participants with articulatory suppression. Holmes and Ellis found a significant effect of AoA with word frequency controlled on category verification speeds when participants were required to say whether a certain picture belonged to a certain category (there were a total of 11 categories in all).[2] Finally, Catling and Johnston (in press) found that pictures with early acquired labels were classified as natural or man-made significantly faster (49 ms) than late acquired items. This AoA effect did not interact with category type in the reaction time data.

The finding of AoA effects in object recognition and categorization tasks suggests that this may be one reason for the AoA effects observed in picture naming. However, the size of these effects is not nearly as large as those reported in picture naming, so it is obviously not the sole reason for the picture naming results. It is especially interesting to compare the results of Catling and Johnston (in press). Using the same pictures, they observed a 123-ms effect of AoA in picture naming but only a 49-ms effect in object categorization. This finding supports the lexical–semantic competition hypothesis (Belke et al., 2005; Brysbaert & Ghyselinck, in press). It should also be noted that the finding of AoA effects in object recognition is as would be predicted by the semantic locus hypothesis and the network plasticity hypothesis. The phonological completeness hypothesis would have a more difficult time explaining these results (however, it cannot be ruled out that phonology is accessed during object recognition).

Word Naming

AoA has been extensively investigated in word naming studies. There are several variants of the word naming paradigm. Usually, a word is presented on a computer screen and a participant is asked to name the word aloud as quickly and accurately as possible. This type of task is referred to here as *immediate naming*. As is described later in this article, the majority of studies using immediate naming have found AoA effects (however, see Treiman et al., 1995, who did not find an AoA effect using a subset of items in a large naming experiment, as well as Lambon Ralph & Ehsan, in press, who failed to find an AoA effect). In one variant of this procedure, there is a deadline to name the word (referred to as *speeded naming*), whereas in another variant, there is a delay between when the word is presented and when the participant must name the word (referred to as *delayed naming*). These types of naming tasks are hypothesized to tap different processes and differ in whether AoA effects are found. For example, Strain, Patterson, and Seidenberg (1995) found different results in an immediate naming versus a speeded naming paradigm when orthogonally manipulating imageability and regularity. They found a main effect of regularity in immediate naming, but not in speeded naming. When required to name a word before a deadline, participants may rely more on the lexical route to phonology, as opposed to a sublexical route. In delayed word naming, on the other hand, word recognition processes should have completed prior to response; thus, any effect of AoA at this stage would be due to the process of initiating articulation itself. Consequently, results from each of these variants on the word naming paradigm are discussed separately here. A summary of results from several recent naming experiments using regression and factorial approaches can be found in Table 3 and Table 4, respectively.

Here the predictions of the different AoA effects on word naming are considered. According to the phonological completeness hypothesis, AoA effects should be robust in immediate word naming, as access to the speech output lexicon is required. Gerhand and Barry (1999a) suggested that the effects of AoA should be larger in speeded word naming than in immediate word naming, as the deadline to name the word should increase the reliance on the speech output lexicon. According to the semantic locus hypothesis, AoA effects may be found in immediate word naming, because Balota et al. (2004) observed semantic effects in word

[2] However, when typicality was also manipulated, no effect of AoA in categorizing pictures was observed by Holmes and Ellis (in press).

Table 4
Results From Recent Word Naming Experiments That Used a Factorial Design

Study	Type	Language	Design	*N*	No. of items	AoA	Frequency	Interaction	Variables controlled
Roodenrys et al. (1994)—Experiment 2	I	English	Partial	15	16/16	31*	37[a]		L, C
Roodenrys et al. (1994)—Experiment 3	I	English	Partial	28	28/28	21*	8		L, C
Morrison and Ellis (1995)	I	English	Partial	21	48/48	32*	1		L, Im
Gerhand and Barry (1998)—Experiment 1	I	English	Full	30	64	14[a]	22*	No	L, Im, C
Gerhand and Barry (1998)—Experiment 3A	I	English	Partial	30	48/48	32*	23*		L, Im
Brysbaert, Lange, and Van Wijnendaele (2000)	I	Dutch	Partial	20	48/48	11[a]	12[a]		L, Im
Barry et al. (2001)[b]	I	English	Partial	24/24	24/24	32*	9		L
Morrison et al. (2002)[c]	I	English	Partial	28	48/48	57*	14*		L, Im
Morrison et al. (2002)[d]	I	English	Partial	32	48/48	29*	−4		L, Im
Ghyselinck, Lewis, and Brysbaert (2004)	I	Dutch	Full	21	96	17*	9	No	L, N
Barry et al. (in press)[e]	I	English	Partial	20	24	27			L, Freq
Havelka and Tomita (in press)—Kanji[f]	I	Japanese	Partial	20	40	102*			Freq, Im
Havelka and Tomita (in press)—Kana[f]	I	Japanese	Partial	20	40	27[a]			Freq, Im
Hernandez and Fiebach (in press)	I	English	Partial	16	96	13*			L, Freq, Im,
Raman (in press)	I	Turkish	Partial	28	50	35*			L, Freq, IM, IPM
Gerhand and Barry (1999a)	S	English	Full	30	64	27*	26*	Yes	L, Im, C
Ghyselinck, Lewis, and Brysbaert (2004)	S	Dutch	Full	23	96	14*	9[a]	No	L, N
Morrison and Ellis (1995)	D	English	Partial	16	48/48	3	−9		L, Im
Gerhand and Barry (1998)	D	English	Full	32	64	−11	−2	No	L, Im, C
Brysbaert, Lange, and Van Wijnendaele (2000)	D	Dutch	Partial	20	48/48	7	3		L, Im
Ghyselinck, Lewis, and Brysbaert (2004)	D	Dutch	Full	17	96	−5	14*	No	L, N

Note. Included are the type of naming study; the language investigated in the study; the type of factorial design used; the number of participants and items contributing to the analyses; the magnitude of the age-of-acquisition (AoA) effect and frequency effect (in milliseconds) and whether these effects, along with an interaction, were significant; and variables that were controlled (either experimentally or statistically). For partial factorial designs, the number of participants and items for both the AoA-manipulated lists and frequency-manipulated lists are presented. If one group of participants named both the AoA and frequency lists, only one number of participants is given in the table. I = immediate naming; L = a measure of word length; C = concreteness; Im = imageability; N = a measure of neighborhood size; Freq = a measure of frequency; IPM = an initial phoneme measure; S = speeded naming; D = delayed naming.

[a] Effect was significant by participants but not by items. [b] Results reported are from Stage 1 of Barry et al. (2001). [c] Results reported are from the young adults in Morrison et al. (2003). [d] Results reported are from the older adults in Morrison et al. (2003). [e] Results reported are from Stage 1 of Barry et al. (in press). [f] In Havelka and Tomita (in press), the type of script (Kanji vs. Kana) was manipulated between participants, so they are presented separately here.

* $p < .05$.

naming, but the effect should be reduced compared with AoA effects in picture naming. The lexical–semantic hypothesis states that AoA effects should be found in immediate word naming; however, this should be a frequency-related AoA effect, and the size of the frequency and AoA effects should be correlated and roughly equivalent. According to the cumulative frequency hypothesis, AoA effects should be found in word naming if cumulative frequency is not controlled. Finally, according to the network plasticity hypothesis, AoA effects should be found in immediate naming; however, the AoA effects should be larger for irregular English words and nontransparent orthographies.

Immediate Word Naming

Immediate word naming studies provide tests for many of the theories discussed. For example, is AoA a stronger predictor of immediate word naming latency than word frequency? According to the lexical–semantic competition hypothesis (Belke et al., 2005; Brysbaert & Ghyselinck, in press), they should be equal predictors. However, many studies have reported AoA effects in the absence of frequency effects, or stronger effects of AoA than word frequency. For example, Gilhooly and Logie (1981b) found AoA to be a significant predictor of word naming latency, even when length, frequency, and familiarity were accounted for. Brown and Watson (1987) investigated the role of AoA on word naming latency by including as predictors rated AoA, written frequency, spoken frequency, concreteness, imageability, and familiarity (in addition to others). AoA was found to be the only significant predictor of naming latency. Neither frequency measure was found to be a significant predictor. However, this is not really surprising because both frequency measures were highly correlated with each other ($r = .70$), and high intercorrelations raise problems with multicollinearity, therefore making significant effects more difficult to find. In a more recent experiment, Morrison et al. (2003) had younger and older adults name verbs. Using a simultaneous multiple regression design, they found AoA to be a significant predictor of verb naming latency for both younger and older adults. Familiarity, word frequency (of the —ing form of the verb), and length were not significant.

Morrison and Ellis (1995) varied the AoA of words while keeping written frequency constant and found a significant effect of AoA on word naming latency. However, they found no significant effect of word frequency on word naming latency when AoA was kept constant. Similarly, Roodenrys, Hulme, Alban, Ellis, and Brown (1994) found a significant effect of AoA on word naming latency when spoken frequency was controlled but only a margin-

ally significant effect of spoken frequency when AoA was controlled.[3]

On the other hand, many studies have reported effects of both AoA and word frequency on immediate word naming latency. For example, Gerhand and Barry (1998) attempted to replicate the Morrison and Ellis (1995) study using the same stimuli and procedure. They too found that there was a significant effect of AoA when frequency was controlled. However, they also found that there was a significant effect of frequency when AoA was controlled. Gerhand and Barry (1998) ruled out several possibilities for why their results differed from Morrison and Ellis's (1995)—such as analysis of arithmetic versus harmonic means, blocking of the items, and participant naming speed—and concluded that there must have been certain undefined procedural differences between the two studies producing the divergent results. Gerhand and Barry (1998) also examined AoA and word frequency effects using a fully factorial design. They found significant main effects of AoA and word frequency and no interaction.

Morrison and Ellis (2000) used the objective AoA norms from Morrison et al. (1997) in a word naming experiment using a multiple regression design. Included as predictors were AoA, a combined written and spoken frequency index, familiarity, word length, and imageability (among others). Among the significant predictors of naming time were objective AoA, word length, and word frequency. This study demonstrated that the presence of AoA effects in word naming was not merely due to the use of a rated AoA variable, and it also demonstrated an independent frequency effect on word naming.

Recent word naming experiments have mostly confirmed the AoA effect on naming time (e.g., Barry et al., 2001; Havelka & Tomita, in press; Hernandez & Fiebach, in press; Raman, in press). Using the stimuli from Morrison and Ellis (1995); Morrison et al. (2002) again found significant AoA effects in word naming with frequency controlled, for both younger and older adults. They also found a significant frequency effect for younger adults but not for older adults. This is interesting in light of the fact that Morrison and Ellis (1995) had originally not found a frequency effect with college-age participants using these stimuli.

In the first stage of their picture naming experiment, Barry et al. (2001) had participants name words that would be repeated as pictures in a second stage. Barry et al. (2001) found a significant effect of AoA in this task. However, in a more recent experiment (Barry et al., in press) in which older and younger adults were participants, the main effect of AoA was not significant in naming for the same set of stimuli. The size of the AoA effect, however, was of roughly the same magnitude in both studies (32 ms vs. 27 ms). It is possible that the inclusion of older adults, who have longer reaction times on average, may have increased the variability, resulting in a failure to find a significant effect.

According to the mapping hypothesis (Monaghan & Ellis, 2002b), AoA effects should be reduced for word naming in transparent orthographies. One such transparent orthography is Italian. Colombo and Burani (2002) investigated AoA's ability to predict naming latencies for Italian nouns and verbs. They found that the best predictor of naming latency for nouns was word length, followed by AoA. For the verbs, the pattern of correlations showed an effect of root frequency, word frequency, and AoA (although these three variables were also highly correlated with each other).

Another such transparent orthography is Dutch. Brysbaert, Lange, and Van Wijnendaele (2000) investigated AoA effects on word naming in Dutch. They manipulated AoA while frequency and imageability were controlled. In a separate experiment, they manipulated frequency while AoA and imageability were controlled. The effect of AoA was significant (by participants) as was the effect of frequency. In a more recent Dutch study, Ghyselinck, Lewis, and Brysbaert (2004) used a fully factorial design to study AoA and frequency effects on immediate naming. Here they found a significant effect of AoA (by participants), but the effect of written frequency failed to reach significance. More recently, the effect of AoA on word naming was investigated in Turkish, which has a completely transparent orthography (Raman, in press). In this experiment there was a 35-ms effect of AoA.

These findings of AoA effects in transparent orthographies would appear to contradict the mapping hypothesis. However, a comparison of the size of the AoA effects is in order. As stated previously, naming has been found to be affected by semantic variables (Balota et al., 2004), and mapping from words to word meaning is an arbitrary mapping. Small AoA effects in naming should thus be predicted, on this basis, in any language. Although it is not possible to compare the size of the AoA effect in Italian reported by Colombo and Burani (2002), because of that study's correlational design, we can compare the average size of the two AoA effects reported in Dutch with the average size of the AoA effects in immediate word naming in English as reported in Table 4. This comparison shows that the average AoA effect reported in Dutch immediate word naming (14 ms) is roughly half of that reported in English (29 ms), a result that is consistent with the mapping hypothesis. The recent results from Turkish (Raman, in press), however, do seem to contradict the mapping hypothesis. The only way to account for these data in terms of the mapping hypothesis is to posit that participants naming Turkish words are more likely to rely on semantics, an arbitrary mapping, compared with participants in other languages.[4]

Also, according to the mapping hypothesis, AoA effects should be larger in naming English words with inconsistent spelling to sound. Monaghan and Ellis (2002b) directly tested this hypothesis by orthogonally manipulating AoA and spelling-to-sound consistency while matching on relevant variables such as length, imageability, number of orthographic neighbors, and two measures of word frequency. They found significant effects of both AoA and consistency. They also found an interaction such that the AoA effect was larger for inconsistent words than for consistent words. This pattern was replicated by Monaghan and Ellis (2002a; however, see Strain, Patterson, & Seidenberg, 2002, and the reply by A. W. Ellis & Monaghan, 2002).

A recent study in Japanese also provides support for the mapping hypothesis. Havelka and Tomita (in press) presented native Japanese speakers with early and late AoA words. Half of the participants received the words written in Kanji, a logographic

[3] Using a different set of materials, Roodenrys et al. (1994) did find significant effects of both frequency and AoA on word naming latency.

[4] Picture naming in Turkish also show a large effect of AoA (138 ms; Raman, 2004). Thus, the pattern of larger effects of AoA in picture naming compared with word naming holds for completely transparent orthographies as well.

system in which the mapping from orthography to phonology is arbitrary. The other half of the participants received the same words written in Kana, which is syllabic with regular mappings from orthography to phonology. The AoA effect was very large and significant in Kanji script (102 ms, the largest AoA effect reported in Table 4). In Kana script, the AoA effect was reduced (27 ms) and was only significant by participants.

Finally, a study by Yamazaki, Ellis, Morrison, and Lambon Ralph (1997) on immediate word naming in Japanese provides some evidence against the phonological completeness hypothesis. The Japanese Ministry of Education keeps records of at what grade level the written form of each Kanji character is taught in school. Therefore, it is possible to dissociate at what age the spoken form of a Japanese word is acquired from when the orthographic character is acquired. Yamazaki et al. found effects of rated spoken AoA, written AoA, and familiarity on naming of single-character Kanji nouns, using simultaneous multiple regressions (however, see Yamada, Takashima, & Yamazaki, 1998; the critique by Shibahara & Kondo, 2002; and Morrison, 2003). This effect of written AoA, over and above spoken AoA, is hard to explain in terms of the phonological completeness hypothesis of AoA. More recently, Shibahara, Zorzi, Hill, Wydell, and Butterworth (2003) factorially manipulated regularity, frequency, and imageability in a Japanese word naming experiment. When AoA was added as a covariate (which turned out to be significant), the significant main effect of imageability that was originally found disappeared.

Speeded Naming

As stated earlier, Gerhand and Barry (1999a) reasoned, according to the phonological completeness hypothesis, that AoA effects should be larger when a deadline to name a word is provided, because of a greater reliance on the speech output lexicon. They also reasoned that the frequency effect should remain roughly the same. Gerhand and Barry (1999a) used the same set of stimuli as in their immediate word naming study to investigate the role of AoA and word frequency in speeded naming. They found a significant main effect of frequency (26 ms), which was about the same size as in immediate word naming (22 ms), and a significant main effect of AoA (27 ms), which was almost twice as large as that found in regular naming (14 ms). In this experiment, the two factors also significantly interacted with each other. This interaction came about because the frequency effect was stronger for late acquired words than for early acquired words. The fact that a stronger AoA effect was found in speeded naming than in immediate naming led Gerhand and Barry (1999a) to conclude that AoA affects the level of lexical phonology activation.

Recently, Ghyselinck, Lewis, and Brysbaert (2004) also examined AoA effects in speeded naming, in Dutch. Using the same set of stimuli as in their immediate naming task, they too found a significant effect of AoA and a significant effect of frequency. Unlike Gerhand and Barry (1999a), they did not find a significant interaction. Also unlike Gerhand and Barry (1999a), their AoA effect in speeded word naming (17 ms) was roughly the same size as their AoA effect in immediate word naming (14 ms).

Delayed Word Naming

A third type of naming experiment imposes a delay between when the stimulus is presented and when the participant is required to produce a name for the stimulus. If an AoA effect is observed in this task, it suggests that AoA exerts its influence on the process of initiating articulation (because processes involved in word recognition should be finished prior to the response). In fact, four studies have provided evidence that there are no AoA effects in this task (Brysbaert, Lange, & Van Wijnendaele, 2000; Gerhand & Barry, 1998; Ghyselinck, Lewis, & Brysbaert, 2004; Morrison & Ellis, 1995). In addition to AoA, frequency effects are not observed in delayed naming for the majority of articles included in the current review (e.g., Brysbaert, Lange, & Van Wijnendaele, 2000; Gerhand & Barry, 1998; Morrison & Ellis, 1995). The one exception is Ghyselinck, Lewis, and Brysbaert (2004), who did observe a significant frequency effect in delayed naming. It should also be noted that AoA effects have also not been found in delayed picture naming (Barry et al., 2001; A. W. Ellis & Morrison, 1998; Holmes & Ellis, in press) as indicated in Table 2.

As a recap, word naming studies provide many tests for AoA theories. First, the phonological completeness hypothesis was not supported by the finding of a written AoA effect in Japanese (Yamazaki et al., 1997) and also was not supported by the finding of an equal effect of AoA in both speeded and immediate naming in Dutch (e.g., Ghyselinck, Lewis, & Brysbaert, 2004). It is difficult to evaluate the cumulative frequency hypothesis, as cumulative frequency was not controlled in any of these studies; thus, it would also predict an AoA effect in the studies. According to both the semantic locus hypothesis and the network plasticity hypothesis, AoA effects should be much smaller in word naming than in picture naming. It is obvious from an examination of Table 4 that this is true. The AoA effect in immediate and speeded word naming is, on average, 31 ms, much smaller than the 125-ms average effect found in picture naming. The mapping hypothesis of the network plasticity theory also suggests that the AoA effect should be reduced in orthographies that are more transparent than English, and with consistent spelling-to-sound words in English. This was true when naming studies in English were compared with naming studies in Dutch. However, the Turkish results (Raman, in press) call into question this hypothesis.

According to the lexical–semantic competition hypothesis, the AoA effect in word naming is a frequency-related effect, so effects of AoA and word frequency should be roughly equivalent and correlated. Although it is true that both the AoA effect and the frequency effect are small in word naming, compared with the AoA effect in picture naming, Table 4 shows that the average AoA effect for immediate and speeded naming is 31 ms, whereas the average frequency effect is smaller at 14 ms. The correlation between frequency and AoA across all naming tasks that manipulated both variables is relatively small, amounting to .35. When delayed naming is removed (because this task usually does not show either effect), the correlation is even further reduced, amounting to .06.

Lexical Decision

Table 5 and Table 6 show results from several recent lexical decision experiments using multiple regression and factorial approaches, respectively. According to the strong form of the phonological completeness hypothesis, AoA effects should not be observed in this task, as it does not require access to the speech output lexicon. According to both the semantic locus hypothesis

Table 5
Results From Recent Lexical Decision Experiments That Used a Regression Design

Study	Type	Language	*N*	No. of items	AoA	Frequency	Interaction	Significant variables	Nonsignificant variables
Morrison and Ellis (2000)	V	English	24	220	Significant	Significant		Im	L, Fam, IPM, N†
Nagy et al. (1989)	V	English	95	168	Significant			SF, AoA^2, L, DF, DF × PS	PS
Bonin, Chalard et al. (2001)	V	French	36	237	Significant	Significant	Significant	L	Fam, IV, BF, N, GPC
Fiebach et al. (2003)	V	German	12	136	Significant	Significant			
Fiebach et al. (2003)	A	German	14	136	Significant	*ns*			

Note. Included are the type of lexical decision task used; the language investigated in the study; the number of participants and items contributing to the analyses; whether a significant age-of-acquisition (AoA) effect, frequency effect, and interaction were found; other variables found to be significant; and other nonsignificant variables included in the equation. V = visual lexical decision; Significant = significant at $p < .05$; Im = imageability; L = a measure of word length; Fam = familiarity; IPM = an initial phoneme measure; N = a measure of neighborhood size; SF = stem frequency; AoA^2 = AoA squared; DF = derivational frequency; PS = part of speech; IV = image variability; BF = bigram frequency; GPC = grapheme-to-phoneme consistency; A = auditory lexical decision.
† $.05 < p < .10$.

and the network plasticity hypothesis, AoA effects should be larger in the lexical decision task than in the naming task, as semantics may be more involved in this task (as indicated by Balota et al., 2004). This effect should also be smaller than in picture naming, as picture naming most likely requires more access to semantics. Again, the cumulative frequency hypothesis predicts AoA effects if cumulative frequency is not controlled. Finally, according to the lexical–semantic competition hypothesis, the size of the frequency and AoA effects should be correlated and roughly equivalent.

Toward the beginning of AoA research, researchers disagreed as to whether AoA affected lexical decision time (LDT). Butler and Hains (1979) included AoA as a variable in a lexical decision experiment along with frequency and length. They found that all three variables significantly predicted LDT in a multiple regression analysis (see also Whaley, 1978). However, Gilhooly and Logie (1982) failed to find a significant effect of AoA in a lexical decision experiment. They found that the significant predictors of LDT were frequency, length, and familiarity and concluded that the reason Butler and Hains found an AoA effect was a failure to control for the familiarity of their items. Likewise, Schwanenflugel, Harnishfeger, and Stowe (1988) also failed to find a significant effect of AoA on LDT when word frequency, length, and context availability were partialed out.[5]

Other researchers have been more successful in finding an AoA effect in lexical decision. Nagy et al. (1989) found effects of AoA with morphologically complex words, even when entered into a regression after the effects due to frequency had been partialed out. Morrison and Ellis (1995) used the same lists of words that they used for immediate and delayed naming as mentioned earlier. They found significant effects of both AoA and frequency.

Turner et al. (1998) also examined AoA and word frequency effects in the lexical decision task. They examined two different types of lexical decision experiments. In the auditory lexical decision experiment, they presented words and nonwords over earphones and the participants had to decide whether what they were hearing was a word or a nonword (by pressing a key). In this experiment, they found a significant effect of AoA when frequency was controlled, but no frequency effect when AoA was controlled. In the visual lexical decision experiment, participants had to decide whether letter strings presented on a computer monitor made up a word or not. Here, Turner et al. found significant effects of both AoA and frequency. The results of Turner et al. are supported by the results of Fiebach, Friederici, Muller, von Cramon, and Hernandez (2003), who had native German speakers perform either an auditory or a visual lexical decision task. Regression analyses showed that whereas both word frequency and AoA significantly predicted LDT for visually presented words, only AoA significantly predicted LDT in the auditory task.

Gerhand and Barry (1999b) used the same set of stimuli from their previous word naming experiments to test the effects of AoA and word frequency in a lexical decision task and observed both AoA and frequency effects, as well as a significant interaction such that the AoA effect was significant only for low-frequency words. Significant effects of AoA and frequency remained even when they manipulated the possible phonological contribution to the lexical decision task by using orthographically illegal nonwords, psuedohomophones, and articulatory suppression exercises.

Recently, Morrison and Ellis (2000) found significant effects of objective AoA, a combined measure of written and spoken frequency, and imageability in a lexical decision task using a simultaneous multiple regression procedure, suggesting that the fact that AoA effects were observed in prior lexical decision tasks was not just due to the reliance on adult ratings. Also, because familiarity was included as a predictor in the regression analysis, the observed AoA effects could not be due simply to a failure to control for familiarity. McDonald and Shillcock (2001) found, by examining correlations with LDT, that AoA was a better predictor of LDT than a variable they called *contextual distinctiveness*, which is based on contextual co-occurrences of words. Recently, Barry et al. (in press) reported a significant effect of AoA with frequency controlled on LDTs in the first stage of their picture repetition experiment.

[5] Context availability is a rated measure of the ease with which context can be generated for a given word. As pointed out by a reviewer, perhaps AoA and context availability are related, such that it is easier to generate context for an early acquired word.

Table 6
Results From Recent Lexical Decision Experiments That Used a Factorial Design

Study	Type	Language	Design	*N*	No. of items	AoA	Frequency	Interaction	Variables controlled
Morrison and Ellis (1995)	V	English	Partial	16	48/48	66*	54*		L, Im
Turner et al. (1998)	V	English	Partial	25/26	66/64	25*	33*		L, N, Im, UP
Turner et al. (1998)	A	English	Partial	20/20	66/64	46*	−8		L, N, Im, UP
Gerhand and Barry (1999b)—Experiment 1	V	English	Full	30	64	59*	77*	Yes	L, Im, C
Bonin, Chalard, et al. (2001)	V	French	Partial	30/30	36/34	56[a]	49*		L, N, BF, GPC
Brysbaert, Lange, and Van Wijnendaele (2000)	V	Dutch	Partial	20	48/48	52*	85*		L, Im
Ghyselinck, Lewis, & Brysbaert (2004)[b]	V	Dutch	Full	20	96	75*	70*	No	L, N
Barry et al. (in press)[c]	V	English	Partial	19	24	74*			L, Freq

Note. Included are the type of lexical decision used; the language investigated in the study; the type of factorial design; the number of participants and items contributing to the analyses; the magnitude of the age-of-acquisition (AoA) effect and frequency effect (in milliseconds) and whether these effects, along with an interaction, were significant; and variables that were controlled (either experimentally or statistically). For partial factorial designs, the number of participants and items for both the AoA manipulated lists and frequency manipulated lists are presented. If one group of participants named both the AoA and frequency lists, only one number of participants is given in the table. V = visual lexical decision; L = a measure of word length; Im = imageability; N = a measure of neighborhood size; UP = uniqueness point; A = auditory lexical decision; C = concreteness; BF = bigram frequency; GPC = grapheme-to-phoneme consistency; Freq = a measure of frequency.
[a] Effect was significant by participants but marginal by items. [b] Results reported are from the lexical decision experiment using legal nonwords in Ghyselinck, Lewis, and Brysboert (2004). [c] Results reported are from Stage 1 of Barry et al. (in press).
* $p < .05$.

Bonin, Chalard, Méot, and Fayol (2001) investigated the influence of AoA on lexical decisions in French. They found significant effects of both AoA and frequency in a partial factorial design. Finally, using a simultaneous multiple regression on the mean LDT responses to 237 words, they found significant effects of AoA and frequency, as well as an interaction such that the AoA effect was significant only for low-frequency words.

Brysbaert, Lange, and Van Wijnendaele (2000) used a partial factorial design to explore AoA's effect on lexical decision in Dutch and found a significant effect of AoA, as well as a significant effect of frequency. Ghyselinck, Lewis, and Brysbaert (2004) used a fully factorial design (with the same items as used in the naming studies mentioned earlier) and three different lexical decision tasks in Dutch. The three tasks differed in the type of nonwords used (illegal, legal, and psuedohomophones). They found significant effects of AoA and frequency in all three tasks. They also did not find significant interactions in any of the tasks. Colombo and Burani (2002) investigated AoA effects on lexical decisions to Italian nouns and verbs. AoA had a strong correlation with LDTs for both nouns and verbs, although more so in the case of verbs.

It appears that the results from most recent experiments converge in finding an effect of AoA on lexical decision. This could be seen as evidence against the phonological completeness hypothesis. However, Gerhand and Barry (1999b) still interpreted their results in lexical decision in terms of a phonological locus, even though AoA effects were observed under conditions used to minimize the reliance on phonological information (e.g., the inclusion of pseudohomophones as nonwords), which is somewhat surprising. In support of both the semantic locus hypothesis and the network plasticity hypothesis, AoA effects are larger in lexical decision (57 ms on average in Table 6) than in word naming but smaller than in picture naming. These results from the lexical decision task also seem to support the idea of a frequency-related AoA effect, as posited in the lexical–semantic competition hypothesis. The size of the AoA effect is pretty equivalent to the size of the frequency effect in lexical decision (51 ms). There is also a stronger correlation between the size of the AoA effect and the size of the frequency effect (.49) than is observed in the naming task. However, the finding from Turner et al. (1998) of a strong effect of AoA with auditory lexical decision but no corresponding frequency effect would be very difficult for the lexical–semantic competition hypothesis to explain.

Eye Fixation Times

All of the aforementioned studies examined AoA effects on word recognition using isolated words. Juhasz and Rayner (2003) recently investigated the effects of AoA and word frequency on word recognition with words embedded in sentence contexts. They recorded eye movements while participants read the sentences. Reading words embedded in sentences is thought to involve access to orthography, phonology, and semantics. They used a simultaneous multiple regression design and included the predictors rated AoA, word frequency, concreteness, length, and familiarity. When Francis and Kucera (1982) written frequency was used, they found significant effects of frequency on first-fixation duration (the duration of the first fixation on the word irrespective of how many fixations the word receives), single-fixation duration (the duration of the fixation on the word if the word receives only one fixation), and gaze duration (the sum of all fixations on the word before the reader's eyes leave the word); they also found significant effects of AoA on single-fixation duration and gaze duration. When the WFG estimates of frequency (Zeno et al., 1995), which are thought to reflect cumulative frequency, were used, AoA still significantly predicted single-fixation duration, whereas cumulative frequency predicted all three fixation-duration measures.

As a follow-up, Juhasz and Rayner (in press) used a partial factorial design with two lists of words. The first list contained words that were varied on AoA and controlled on several measures of frequency (including cumulative frequency) as well as concreteness, familiarity, and length. The second list of words varied on several measures of word frequency but was controlled on AoA, concreteness, and length. For AoA, there were significant effects for first-fixation duration, single-fixation duration, and gaze duration. For word frequency, there was a significant effect for first-fixation duration and single-fixation duration but only a marginally significant effect for gaze duration. These two studies both show an effect of AoA over and above effects attributable to cumulative frequency.

Face Recognition

AoA has also been investigated in face recognition experiments. Prior to this AoA work, Valentine and Moore (1995) found that both facial distinctiveness and surname frequency affected famous face naming latency when AoA was not controlled. Specifically, low-frequency surnames were produced faster than high-frequency surnames. Surname frequency was tabulated by counting occurrences in a telephone directory. Although this method probably does not give a completely accurate account of surname frequency (as different telephone directories will vary in the frequency of occurrences of names), Moore and Valentine (1998) reported correlations of .87 and higher between the frequency of occurrence from the telephone directory they used and three other telephone directories. Note, however, that this measure does not take into account that some surnames will be encountered very frequently in print and spoken language (e.g., celebrity names), even though the names may not be as common as indexed by a telephone directory. Moore and Valentine also had participants rate at what age they first encountered the faces of celebrities, as well as their familiarity with the celebrity (which they argued represented cumulative frequency) and the celebrity's facial distinctiveness. They then had the same participants name the faces (thus participants were familiarized with the pictures prior to naming them). Only AoA and familiarity were significant predictors of naming latencies (surname frequency and facial distinctiveness were not significant, failing to replicate Valentine & Moore, 1995). The AoA effect was replicated in two subsequent factorial experiments (where AoA was manipulated with other variables controlled).

As Lewis (1999a) pointed out, there are many difficulties in designing a famous face study, such as obtaining enough images that people can recognize (this may be what led to the 43% data loss that Moore & Valentine, 1998, reported for one of their experiments). In order to rectify this difficulty, Lewis (1999a) designed a famous face categorization experiment in which faces of actors had to be categorized as belonging to one of two TV shows and in which participants had to be regular watchers of both shows. After this categorization, participants were asked to rate the frequency with which each of the characters appeared on his or her show. The three variables included in the regressions were the period of time the characters were on the show, the period of time since they left, and the frequency of the character on the show. All three variables significantly predicted categorization speed. AoA was also found to be a significant predictor of reaction time when used in a regression equation. However, Lewis (1999a) attributed this AoA effect to cumulative frequency of exposure of the famous faces. Moore, Valentine, and Turner (1999) critiqued Lewis's (1999a) interpretation based on several points such as the fact that in Moore and Valentine, an AoA effect was still observed when rated familiarity (which may reflect the amount of encounter with a celebrity) was controlled (see Lewis, 1999b, for a reply to Moore et al., 1999).

In a similar study, Lewis et al. (2002) had both younger and older adults classify current characters as belonging to one of the two TV shows. For older and younger adults, both the period of time that the character has been on the show and the frequency with which the character appears were significant predictors of categorization speed. Of importance, the famous face categorization tasks do not require access to phonology, so an effect of AoA in these studies cannot be explained in terms of the phonological completeness hypothesis. A discussion of whether these results truly reflect cumulative frequency is presented later in the Evaluation of AoA Theories section.

Other Tasks

Over the years, AoA has been studied in several other tasks that deserve mention here. Evaluating results from these tasks is helpful in differentiating among the five theories of AoA effects.

Category exemplar generation. One article that is often cited with reference to early AoA effects is Loftus and Suppes (1972), although AoA itself was not directly measured. In Loftus and Suppes, participants were presented with a category and a letter (such as *fruit–P*) and had to provide an exemplar (such as *peach*). Note that this study was published prior to Carroll and White's (1973b) article on AoA, which introduced the idea of AoA ratings. Instead, they used the Thorndike–Lorge (1944) juvenile count to estimate two variables, what they termed the *children's frequency of the category* and the *children's frequency of the response*.[6] These variables can be thought of as providing a type of AoA measure. The idea is that words occurring with a high frequency in the juvenile count (which is a frequency count of only books recommended for Grades 3 to 8) are acquired earlier than those that occur with a relatively low frequency in the count. These two variables were entered second and third into a stepwise regression and dramatically increased the variance accounted for (the R^2). A new study by Catling and Johnston (2005) used the same task as Loftus and Suppes but explicitly manipulated AoA. A significant AoA effect (167 ms) was found on the latency to provide a response when frequency was controlled. However, there was no significant effect of frequency with AoA controlled. This finding supports the lexical–semantic competition hypothesis, as a unique lemma had to be selected in order to provide a category exemplar (Belke et al., 2005).

Anagram solution. Stratton et al. (1975) reported that rated AoA predicted anagram solution difficulty. However, Gilhooly and Johnson (1978) failed to find such an effect. Gilhooly and Gilhooly (1979) did find that AoA (along with frequency and other

[6] For example, the children's category frequency is the frequency of the category label (e.g., *fruit*) in the Thorndike–Lorge (1944) juvenile count. The children's response frequency is the frequency of the most highly frequent possible response in the juvenile count.

variables) was a significant predictor of how many people provided the target word when prompted with an initial bigram.

Perceptual identification of words. Lyons, Teer, and Rubenstein (1978) found a significantly lower recognition threshold using a tachistoscopic presentation for early acquired words compared with late acquired words when frequency was controlled. However, Gilhooly and Logie (1981b) failed to find an effect of AoA on auditory recognition thresholds, and Gilhooly and Logie (1981a) failed to find an AoA effect on visual recognition thresholds. These results led to the conclusion that AoA affects word production but not recognition (see Gilhooly & Watson, 1981, for a review of this position). More recently, Ghyselinck, Lewis, and Brysbaert (2004) found significant effects of both AoA and word frequency on perceptual identification of briefly presented and masked words, thus suggesting that AoA may be related to the ability to identify briefly presented words.

Gender monitoring. In the Italian language (as well as other European languages) nouns are marked for gender. Bates, Devescovi, Pizzamigilio, D'Amico, and Hernandez (1995) showed that AoA (measured as whether the nouns came from child or adult frequency indices) made a significant independent contribution to the time it takes to correctly make a decision about the gender of nouns in a gender monitoring task but not the time it took to repeat a word that was aurally presented. According to the network plasticity hypothesis, this is not surprising, as the decision of gender in Italian should be an arbitrary mapping, but repeating an aurally presented word in Italian would be a consistent mapping.

Word pronunciation durations. Gerhand and Barry (1998) investigated the role of AoA and frequency on word pronunciation durations (where a participant must verbally repeat a word 10 times in a row as quickly as possible) using the same set of stimuli as in their naming experiments. In this task, they found a significant 36-ms effect of AoA. The 6-ms effect of word frequency was significant by participants, but not by items, as was the interaction between the two variables. It is interesting to note that this interaction was in the reverse direction from the interaction found by Gerhand and Barry (1999a) in speeded word naming. In the word pronunciation task, the frequency effect was significant only for the early acquired words. Using the stimuli of Morrison and Ellis (1995), Gerhand and Barry (1998) also found a significant effect of AoA (19 ms). The 5-ms frequency effect was significant only in the participant's analysis and was actually in the reverse direction to that usually observed. Gerhand and Barry (1998) interpreted these findings as suggesting that although word frequency is an input variable and does not affect word pronunciation durations, AoA influences the phonological output. This finding would appear to be problematic for the lexical–semantic hypothesis, as an AoA effect was found in absence of a frequency effect. However, in an earlier speech rate experiment conducted by Roodenrys et al. (1994) in which the time it took participants to repeat a word 10 times was measured, the results were inconsistent. With one set of words, Roodenrys et al. found a significant effect of AoA but not frequency. In an additional experiment using the same task with two larger sets of words, Roodenrys et al. found a significant effect of frequency on speech rate but only a marginal effect of AoA.

Word segmentation. Monaghan and Ellis (2002a) had participants read words to themselves. Immediately following the words, participants were presented with a segment of the words and asked to pronounce the sound of the remaining part of the word. The latency to respond was used as the dependent measure. Sets of words varied in AoA and where the segmentation position was. No main effect of AoA was found in this task. This provides the strongest evidence against the phonological completeness hypothesis.

Word translation tasks. D. J. Murray (1986) had English–French bilinguals translate words from either their first language or second language. Using a stepwise multiple regression, first-language (English) AoA was a significant predictor of the speed of translation from French to English (as was word frequency). Izura and Ellis (2004) criticized several aspects of D. J. Murray's experiment, such as the use of stepwise regression, the failure to include second-language AoA, and the small sample size (11 participants). Izura and Ellis (2004) had 20 native Spanish speakers (who were also fluent in English) decide whether two presented words (one in Spanish and one in English) were translation equivalents. They found a significant effect of second-language AoA on reaction times. There was also an interaction between the first-language and second-language AoA, such that first-language AoA had an effect only when the second-language words were early acquired. However, in another experiment, when the English word was presented for 400 ms prior to the Spanish word, effects of both Spanish and English AoA were found, and there was no interaction (see also Izura & Ellis, 2002).

Semantic tasks. AoA effects have been observed in some types of semantic tasks, lending credence to the semantic locus hypothesis. For example, Brysbaert, Van Wijnendaele, and De Deyne (2000) reported a significant effect of AoA (as well as imageability and a reverse frequency effect) on the time it took participants to produce an associate to a stimulus word. In addition, using the same words, Brysbaert, Van Wijnendaele, and De Deyne (2000) presented participants with either proper names (such as *Nadia*) or words with definable meanings. Participants were asked to categorize the words. They found effects of both AoA and word frequency on reaction time. Ghyselinck, Lewis, and Brysbaert (2004) replicated this effect by using a fully factorial design. They again found significant effects of AoA and frequency on the time to classify the words.

Recently, Ghyselinck, Custers, and Brysbaert (2004) investigated the role of AoA in the semantic Simon paradigm. In the paradigm, participants are visually presented with words, half of which are in uppercase and half of which are in lowercase. The participant's task is to say "living" or "nonliving" depending on the case of the words. Half of the words refer to living things, and the other half refer to nonliving things. A congruency effect (measured as the difference in response time if the category matches the meaning of the words compared with when the category does not match) suggests that the meanings of the words are automatically accessed, even when meaning activation is not necessary for (and even hinders) the task. Ghyselinck, Custers, and Brysbaert (2004) used 44 early acquired words and 44 late acquired words (half of each referred to living things, whereas the other half did not) that were matched on frequency, familiarity, and length. They observed a congruency effect of 50 ms for early acquired words that was twice as large as the congruency effect for late acquired words. They interpreted this finding as indicating that the meanings of early acquired words are accessed faster than those of late acquired words. Morrison and Gibbons (in press) asked participants to categorize written words as belonging to the

category living or nonliving. In two experiments using simultaneous regressions, Morrison and Gibbons observed significant AoA effects. However, these effects were only significant for the living things category.

Belke et al. (2005) used a variant of a picture naming experiment, called the semantic blocking paradigm, where the effects of semantic context on picture naming can be investigated. In this paradigm, participants are presented with pictures to name in either a homogeneous semantic context (e.g., all pictures are animals) or a heterogeneous semantic context. Previous findings have shown that participants are slower to name the pictures in a homogeneous context compared with the same pictures in a heterogeneous context. This is predicted to occur because the lemmas for semantically related lemmas are hypothesized to compete with each other for selection. Belke et al. hypothesized that the lemmas for early acquired words may be stronger competitors for selection than the lemmas for late acquired words. Therefore, a larger semantic blocking for late acquired words (because they have more competition from the early acquired lemmas) is predicted. This is exactly the pattern of results that they obtained, providing support for the lexical–semantic competition hypothesis.

Generality of AoA Effects

As mentioned in the introduction, many psycholinguistic researchers and models of lexical processing do not take AoA effects into account. Part of this may be due to the fact that the locus of AoA effects has been difficult to pin down, and many researchers still believe that AoA effects are reducible to frequency effects. Another possible reason may be a perceived lack of generality of AoA effects. Many studies have found AoA effects on lexical processing tasks in English using simple nouns and only young adults. It should be clear from reading the preceding part of the review that AoA effects are found in many different languages other than English. The purpose of this section is to further illustrate the generality of AoA effects.

Word Stimuli

There are some studies that have found AoA to significantly affect the processing of words other than simple nouns. First, as mentioned previously, Nagy et al. (1989) found AoA effects with morphologically complex words. There has also been recent interest in generalizing AoA effects to naming action pictures (verbs) as opposed to just object naming (nouns). Bogka et al. (2003) investigated the role of AoA in naming both objects and actions represented in pictures. In an experiment with English-speaking participants, they used three levels of AoA (later, early, and very early) and two types of pictures (object and action) and found significant differences between the three AoA groups for both the object and action pictures, even when effects due to imageability and visual complexity were covaried out. In another experiment, they used Greek participants and only two AoA groups, late and early. There was again a significant effect of AoA for both picture types, even with imageability and visual complexity covaried out. Post hoc simultaneous multiple regressions showed effects of AoA, imageability, and visual complexity in all experiments, whereas frequency was only significant for Greek participants.

In a similar study, Morrison et al. (2003) asked both older and younger adults to name pictures depicting an action. They performed a simultaneous multiple regression on the mean naming latency for each picture, separately for younger and older adults. For both younger and older adults, AoA and a measure of name agreement were the only significant predictors. Morrison et al. (2003) also had younger and older adults name the visually presented verbs that were used in the action pictures. Using a simultaneous multiple regression design, they found AoA to be a significant predictor of verb naming latency for both younger and older adults.

Finally, whereas the majority of studies examining AoA have presented words in isolation and required some type of response to be made, Juhasz and Rayner (2003, in press) have found that AoA effects generalize to sentence reading, even when cumulative frequency is controlled. Thus, AoA is an important variable in natural reading and is not merely an artifact of the tasks being used to investigate it.

Episodic Memory Tasks

The section on face recognition demonstrated the importance of AoA in tasks using stimuli other than words. There is also evidence that AoA has an effect on episodic memory as well, although there have been debates about the reality of this effect in the literature. Gilhooly and Gilhooly (1979) carried out the first investigation of AoA effects in episodic memory tasks. They used a stepwise regression procedure in which each word was given a score related to how many people recalled or recognized it. They found that only serial position in the list and imagery significantly predicted recall performance, whereas only written frequency significantly predicted recognition performance. They concluded that AoA does not affect episodic memory. Morris (1981) criticized Gilhooly and Gilhooly's (1979) method of analysis on the grounds (also discussed at the beginning of this article) that stepwise multiple regression designs are problematic for studying AoA, word frequency, and other related variables because of the high intercorrelations between them. Morris (1981) pointed out that Gilhooly and Gilhooly (1979) used a stepwise regression technique in their analysis of the recognition data in which they entered frequency as the first variable (although there is really no strong theoretical reason to do so). Morris (1981) then reported his own experiment examining AoA effects in recall and found a significant AoA effect on recall performance such that there was better recall for late acquired words compared with earlier acquired words.

Like Gilhooly and Gilhooly (1979), V. Coltheart and Winograd (1986) examined the effects of AoA on recall and recognition and found no effect of AoA on recall performance when frequency or imageability was controlled. V. Coltheart and Winograd concluded that Morris (1981) confounded AoA with the emotional context of his words, as more late acquired words had a high emotional content associated with them and this may have led to an apparent AoA effect.

The results from these studies are contradictory. However, Dewhurst, Hitch, and Barry (1998) pointed out that in Morris's (1981) experiment, the study list was mixed with late and early AoA words, whereas in V. Coltheart and Winograd's (1986) recall experiment, participants studied pure lists of early and late AoA

words. Dewhurst et al. argued that previous studies examining frequency effects in recall have suggested that the composition of the study list can influence whether or not a frequency effect is found, so the same might be true for AoA. They directly tested this hypothesis in their Experiment 3, in which they had half of their participants study mixed lists of words orthogonally varying on AoA and word frequency. The other half of the participants studied pure lists from one of the four conditions. For the mixed lists group, significantly more late acquired words were recalled compared with early acquired words and significantly more low-frequency words were recalled compared with high-frequency words. There was also no interaction between the two variables. For the group of participants studying the pure lists, there was a frequency effect, but no AoA effect. Thus, Dewhurst et al. demonstrated that the differences in whether AoA effects are observed can be due to how the stimuli are presented.

Dewhurst et al. (1998) also reported a recognition experiment in which participants had to make an old–new judgment and a remember–know judgment. In this paradigm, a remember response means that the participant has a definite recollection of the word occurring on the list, and a know response means that the participant thinks the item was on the list but has no direct recollection of the item. In their first experiment, they factorially manipulated AoA and frequency using Gerhand and Barry's (1998, 1999a, 1999b) stimuli. For remember responses they observed significant effects of frequency (low-frequency words were correctly recognized more often than high-frequency words) and AoA (late acquired words were correctly recognized more often than early acquired words) and no interaction. For know responses, there was a reverse main effect of frequency (with high-frequency words receiving more know responses) and no effect of AoA. On the basis of the fact that AoA affected only remember responses, Dewhurst et al. concluded that AoA affects the recollective component of episodic memory and has similar but noninteracting effects compared with frequency. Thus, AoA does seem to play a role in episodic memory.

AoA Effects in Different Participant Populations

The majority of experiments studying AoA effects have been done with healthy college-age participants. This review is mainly concerned with those studies. However, many studies have also examined AoA effects in special populations such as children (e.g., Assink, van Well, & Knuijt, 2003; Baddeley, Logie, & Ellis, 1988; Baumeister, 1984; Brysbaert, 1996; Cirrin, 1984; V. Coltheart, Laxon, & Keating, 1988; D'Amico, Devescovi, and Bates, 2001; Garlock, Walley, & Metsala, 2001; Johnson & Clark, 1988; Klose, Schwartz, & Brown, 1983; Nazir, Decoppet, & Aghababian, 2003; Walley, 1993; Walley & Metsala, 1990, 1992; Winters & Brzoska, 1975; Winters, Winter, & Burger, 1978), older adults (e.g., Barry et al., in press; Baumgaertner & Tompkins, 1998; Hodgson & Ellis, 1998; Lewis et al., 2002; Morrison et al., 2002, 2003), and patients with various disorders (e.g., Barry & Gerhand, 2003; Bell, Davies, Hermann, & Walters, 2000; Cuetos, Aguado, Izura, & Ellis, 2002; Feyereisen et al., 1988; Forbes-McKay, Ellis, Shanks, & Venneri, 2005; Frol et al., 2001; Gerhand & Barry, 2000; Hirsh & Ellis, 1994; Holmes, Fitch, & Ellis, in press; Kay, Hanley, & Miles, 2001; Kremin et al., 2001; Lambon Ralph, Graham, Ellis, & Hodges, 1998; Rochford & Williams, 1962; Sage & Ellis, 2004; Sullivan Giovanello, Alexander, & Verfaelli, 2003; Taylor, 1998; Ukita, Abe, & Yamada, 1999; Weekes, Davies, Parris, & Robinson, 2003; Winters & Brzoska, 1975; Winters & Burger, 1980; Winters & Cundari, 1979; Winters, Hoats, & Kahn, 1985). These studies do provide insight into the nature of the AoA effect and deserve to be mentioned in any thorough review of AoA effects. The purpose of this section is to merely outline the results of some of the published studies that explore AoA effects in different populations. This section is not meant to be an exhaustive review of AoA effects in special populations (for a review of AoA effects in people with acquired language impairments, please see Barca & Burani, 2002); it is simply meant to make researchers aware of the rich literature on AoA effects outside of healthy adult processing.

Developmental Studies

Walley and colleagues have provided much insight into AoA effects in young children. Walley and Metsala (1992) had 5-year-olds and 8-year-olds rate at what age they learned a word or, if they had not learned the word yet, when they estimated that they would learn it. The correlations of AoA ratings between 5-year-olds and adults, 8-year-olds and adults, and 5-year-olds and 8-year-olds were .88, .90 and .91, respectively, suggesting that both children and adults have enough metalexical knowledge to be able to rate their AoA of words. Another group of 5-year-olds then performed a mispronunciation detection task. In this task, correct responses significantly decreased with increasing AoA. Two separate stepwise regressions were performed, one including the 5-year-olds' AoA estimates along with other variables and one including the adults' AoA estimates with other variables. The 5-year-olds' AoA estimates were found to account for 43% of the variance in performance, and the adult AoA estimates were found to account for 35% of the variance in performance (for more developmental AoA research, see Garlock et al., 2001; Walley, 1993; Walley & Metsala, 1990; Walley, Metsala, & Garlock, 2003).

Baumeister (1984) had students complete verbal learning tests at 6-month intervals in a longitudinal study, starting in the first grade so that actual AoA values were known. When the students reached the ninth-grade, they were asked to name early and late acquired words that were tachistoscopically presented. Early acquired words had shorter thresholds than late ones. However, when a measure of meaningfulness was covaried out, there was no longer any effect of AoA. Baumeister concluded that the reason AoA effects occur is that early acquired words have more associations in the semantic network (a conclusion supported by the modeling work of Steyvers & Tenenbaum, 2005).

In an auditory lexical decision task, Cirrin (1984) showed AoA to significantly predict reaction time for adults, first graders, and kindergartners. Butterfield and Butterfield (1977), while not manipulating AoA, showed participants (ranging from ages 4 to 70) pictures and asked them to name them. They found that the amount of name agreement in adults predicted the age at which children started to use the same name, thus showing a relationship between object codability and age. They argued that this adds validity to studies finding AoA effects with adults. Winters and Brzoska (1975) found AoA to have a significant effect on naming accuracy for kindergartners, fourth graders, and ninth graders when frequency was partialed out (see also Winters et al., 1978).

AoA has been found to be an important variable in older adults as well. Many of these studies were mentioned in previous sections. In addition to these, Hodgson and Ellis (1998) had older adults (ages 71–86) name pictures that varied on many factors including frequency and objective AoA (taken from Morrison et al., 1997). AoA was a significant predictor of names correctly produced within 5 s and within 15 s for the older adults in this study. Baumgaertner and Tompkins (1998) found that AoA was a significant predictor of auditory LDTs for adults ages 52 to 74 with frequency controlled for statistically.

Patient Studies

There has been a good deal of research examining what variables, including AoA, affect naming accuracy in patients with specific ailments. In a study that examined 9 patients with semantic dementia, both AoA and frequency were found to influence picture naming accuracy (Lambon Ralph et al., 1998). Similarly, AoA and familiarity were found to be significantly correlated with picture naming accuracy in dementia when 116 patients were studied (Taylor, 1998).

AoA has also been found to be a significant predictor of naming accuracy in patients with Alzheimer's disease (Kremin et al., 2001; Silveri, Cappa, Mariotti, & Puopolo, 2002). Recently, Holmes et al. (in press) investigated AoA effects in the categorization of pictures of real objects versus nonobjects and naming of the real objects. A partial factorial approach was taken, where AoA of the real object pictures was manipulated with frequency controlled. Patients with Alzheimer's disease showed a significant effect of AoA in object categorization (control participants did not). Also, in picture naming, patients with Alzheimer's disease showed a larger effect of AoA in picture naming accuracy than control participants (although the AoA effect was significant in both).

Forbes-McKay et al. (2005) had patients with Alzheimer's disease and control participants complete a semantic fluency task in which they were required to generate as many words as possible belonging to two categories (animals and fruit) in 1 min. Their responses were then scored for length, frequency, typicality, and AoA. Using a discriminant function analysis, the AoA of words produced was shown to be able to classify patients 88% correctly and controls 95% correctly. From this study it appears that AoA of words produced in a semantic fluency task may be able to discriminate patients with Alzheimer's disease from healthy controls and thus may be a good tool in diagnosing early Alzheimer's disease.

Word frequency has long been known to be related to the difficulty patients with aphasia have in naming items (Rochford & Williams, 1965). Several studies have also suggested that AoA affects aphasic naming accuracy. In a case study by Hirsh and Ellis (1994), AoA was found to be a significant predictor of both spoken and written picture naming, whereas frequency was not. Likewise, Hirsh and Funnell (1995) found AoA to affect confrontation naming performance of a patient with aphasia. In a study that tested two groups of patients with aphasia, Nickels and Howard (1995) found that picture naming accuracy of both groups was predicted by AoA, but not by frequency. AoA did not significantly predict phonological errors but did significantly predict semantic errors. Similarly, a case study of a woman with deep dyslexia demonstrated that semantic errors when naming words were significantly more likely to occur with early acquired words compared with late acquired words (Gerhand & Barry, 2000). Together, these results provide support for a semantic locus of AoA effects.

Conclusions

Although many researchers may have wished to dismiss AoA effects as simply artifacts of word familiarity or frequency, what the literature shows is that the AoA effect is a very robust phenomenon that is found in many different types of tasks, with a wide variety of languages and participant populations. In fact, in the literature reviewed here, the AoA effect is almost always found, whereas the often-cited frequency effect appears to be more elusive (especially in the case of picture naming). I believe the above review has demonstrated the robustness of the AoA effect. The question still remains, however, as to why AoA effects occur. The next section evaluates the main theories of AoA based on the experimental results already outlined.

Evaluation of AoA Theories

In this section, experimental evidence providing support for and against the five main AoA theories (phonological completeness hypothesis, cumulative frequency hypothesis, semantic locus hypothesis, network plasticity hypothesis, and lexical–semantic competition hypothesis) is evaluated.

Phonological Completeness Hypothesis

The phonological completeness hypothesis predicts an AoA effect in tasks requiring a verbal response. Although it is true that AoA effects are reliably observed in such tasks, as noted earlier, it is clear that AoA effects are observed in tasks not requiring verbal responses as well, such as lexical decision. Because AoA effects have been found in the lexical decision task, researchers in favor of the phonological completeness hypothesis claim that the AoA effect resides not necessarily in the speech output lexicon but simply in the accessing of a word's stored phonological representation. The underlying assumption here is, of course, that the lexical decision task requires the retrieval of stored phonological representations (Gerhand & Barry, 1999b). Gerhand and Barry's (1999b) position is somewhat surprising given that AoA effects were observed in lexical decision even when conditions minimizing reliance on phonological information were used (by manipulating the type of nonwords; see also Ghyselinck, Lewis, & Brysbaert, 2004). Also, the phonological completeness hypothesis should not predict larger AoA effects in some tasks requiring verbal responses compared with other tasks, as is the case with picture naming compared with word naming.

Since the original proposal of this theory, new experiments have also shed doubt on the validity of the phonological completeness hypothesis. As mentioned previously, Lewis (1999a) found an AoA effect on famous face categorization, a task that does not require access to phonology. Also, the finding of a written AoA effect in the naming of Japanese Kanji (Yamazaki et al., 1997) sheds doubt on the phonological completeness hypothesis. In addition, Assink et al. (2003) observed an AoA effect in a lexical decision task using English words for nonnative speakers who had learned the language relatively late (at age 12 or later). According

to the phonological completeness hypothesis, AoA effects should not be observed for this group of participants, as they learned the language past the age at which holistic phonological representations would be formed. The strongest evidence against the phonological completeness hypothesis was provided by Monaghan and Ellis (2002a). They found no link between participants' ability to segment words and the AoA of those words. If the phonological completeness hypothesis were correct, people should have more difficulty segmenting early acquired words because these should be represented in a holistic manner.

It should be noted, however, that although the phonological completeness hypothesis may be ruled out, this does not mean that AoA has no effect on accessing stored phonological representations. Results from a recent neuroimaging study (Hernandez & Fiebach, in press) suggest that naming late acquired words activates areas of the brain thought to be related to phonological processing to a greater extent than naming early acquired words.[7] The network plasticity account of AoA effects (A. W. Ellis & Lambon Ralph, 2000) also suggests that AoA will affect phonological processing. This effect should be larger in the case of irregular spelling-to-sound correspondences according to the mapping hypothesis (e.g., Monaghan & Ellis, 2002b).

Cumulative Frequency Hypothesis

According to the cumulative frequency hypothesis, apparent AoA effects are observed because words acquired early in life have been encountered more often in a person's lifetime than words acquired later. Thus, it is not the age at which the word was acquired, or the order of acquisition, but the number of encounters with the word over the life span that leads to an apparent AoA effect. According to the cumulative frequency hypothesis, AoA effects should be observed when cumulative frequency is not controlled. Unfortunately, the majority of the studies reviewed in this article did not control for cumulative frequency. One exception is the eye movement studies of Juhasz and Rayner (2003, in press) in which AoA was found to affect eye fixation durations over and above cumulative frequency (as measured by the norms of Zeno et al., 1995). In addition, new research conducted in French by Bonin, Barry, Méot, and Chalard (2004) demonstrated significant effects of objective AoA in word naming, picture naming, written picture naming, and lexical decision in regression equations with cumulative frequency included as a predictor.

Other experiments, albeit not controlling for cumulative frequency, have tested predictions drawn from the cumulative frequency hypothesis. For example, if observed AoA effects are due to differences in word residence time (the amount of time that a word has been known), then the AoA effect should get smaller as people get older, as long as frequency is held constant. A study by Morrison et al. (2002) directly tested this prediction by having younger and older adults name pictures and words that differed on AoA but were matched on frequency. Although the AoA effect did decrease slightly with age, it was significant in all age groups and AoA did not significantly interact with age group. Morrison et al. (2002) interpreted this finding as evidence against the cumulative frequency hypothesis (see also Barry et al., in press).

Stadthagen-Gonzalez, Bowers, and Damian (2004) also provided evidence against a cumulative frequency account of AoA effects by investigating lexical decision performance of experts in the fields of psychology and chemistry. Both word frequency and AoA were manipulated. The low-frequency and high-frequency late acquired conditions actually consisted of the same words. What made the words low or high in frequency was the expertise of the participant. For example, the word *cognition* was late acquired and calculated to have a high frequency for psychology experts, but a low frequency for chemistry experts (the frequencies were calculated based on number of occurrences in academic journals). Conversely, the word *molecular* was late acquired with a high frequency of occurrence for chemistry experts but a low frequency of occurrence for psychology experts. Performance on these late acquired words was compared with performance on early acquired high-frequency words (such as *telephone*) and early acquired low-frequency words (such as *bubble*). Cumulative frequencies were also estimated for these items, with the late acquired high-frequency words estimated as having a higher cumulative frequency than the early acquired low-frequency words. In this experiment, late acquired high-frequency words were responded to significantly faster than late acquired low-frequency words, strongly supporting a role for adult frequency. Performance on late acquired high-frequency words was also significantly worse than performance on early acquired high-frequency words, supporting a role for AoA. Most important for the present discussion, although the late acquired high-frequency words were estimated to have a higher cumulative frequency, the LDTs for these words did not differ from the LDTs for early acquired low-frequency words.

As mentioned earlier, Lewis (1999a, 1999b; Lewis et al., 2001) has been a major advocate for a cumulative frequency account of AoA. Lewis et al. (2001) used the cumulative frequency formula outlined earlier, $ln(Rt) = -A\ ln(freq) - A\ ln(Age - AoA) + ln(k)$, to reanalyze the item means from the original AoA experiment by Carroll and White (1973b). They found that $ln(freq)$ and $ln(Age - AoA)$ were both significant predictors of picture naming latency. Using this equation also increased the percentage of variability accounted for (R^2) as compared with the original analysis, but the significance of this increase was not tested. Also, they found that if Carroll and White (1973b) had analyzed their data on the raw reaction times (instead of the reciprocal reaction times), then an interaction between frequency and AoA would have been significant. The failure to find an interaction in these early experiments resulted in the rejection of the cumulative frequency idea. If Carroll and White (1973b) had found an interaction, the cumulative frequency idea might have been embraced much earlier on.

Ghyselinck, Lewis, and Brysbaert (2004) recently provided evidence against Lewis et al.'s (2001) cumulative frequency hypothesis. According to the hypothesis, the coefficient for the frequency and the word residence time component should be the same. As mentioned previously, the cumulative frequency account is an instance-based account, where effects are driven by how often a person encounters a certain word. The more instances a person has with a certain word, the better his or her performance. Whether the increase in instances comes from a longer word residence time or

[7] The neuroimaging results of Fiebach et al. (2003) showed a different pattern of activities for early and late words. Hernandez and Fiebach (in press) suggested that this may be due to the difference in language (German vs. English) or the difference in tasks (word naming vs. lexical decision).

a larger frequency of occurrence does not matter according to the theory. Because both word residence time and frequency of occurrence should have equal importance in determining the effects, they should have equal weighting. However, in seven different experiments, they found the coefficient for word residence time to be roughly 10 times larger than that for frequency, indicating that the amount of time that a word is known plays more of a role than the frequency with which a word is encountered. This also brings up a related point, discussed by Brysbaert and Ghyselinck (in press), that according to the logic of the cumulative frequency hypothesis, word frequency effects should be larger, on average, than AoA effects because the range of frequencies used in tasks is often larger than that of AoA. However, as made obvious by the present review, this is not the case. Lewis et al. (2002) also provided more evidence against Lewis's own theory (Lewis, 1999a, 1999b; Lewis et al., 2001): In a face categorization experiment, they found the coefficient for the time the character was known (which is equivalent to word residence time) to be significantly larger than that for frequency for older adults, suggesting that his original hypothesis was not correct.

Research with connectionist modeling has also provided insight into the respective roles of cumulative frequency and AoA.[8] A. W. Ellis and Lambon Ralph (2000) were the first researchers to attempt to model AoA effects in a connectionist framework. They used a three-layer network (input layer, hidden units layer, and output layer) with back-propagation. Morrison and Ellis (1995) originally believed that AoA effects could not be modeled in connectionist frameworks because in such models, if a first set of patterns is learned and then a second set is learned, performance on the first set is usually worse. This is the opposite of what is found in the AoA literature, in which an advantage is usually seen for earlier acquired items. When a new set of items replaces an old set of items in training, this is referred to as *focused training*. In fact, when A. W. Ellis and Lambon Ralph used this training scheme, they did not find AoA effects in the model. In comparison to this, when they used an interleaved training scheme, where the late acquired words did not replace the early acquired words, an AoA effect was found. This type of interleaved training is what happens in normal vocabulary development.

In one simulation, A. W. Ellis and Lambon Ralph (2000) investigated the joint effects of frequency and AoA where half of the early and late trained patterns were trained at a relatively high frequency and half were trained at a relatively low frequency. They found significant effects of AoA and word frequency and no significant interaction between the two variables, although the interaction approached significance when the ratio of high-frequency to low-frequency training was 10:1 as opposed to 3:1. This fact led A. W. Ellis and Lambon Ralph to conclude that when the frequency manipulation is strong, AoA and frequency may interact.

A. W. Ellis and Lambon Ralph (2000) then conducted two other simulations in order to test the cumulative frequency account of AoA. In the first of these simulations, training was extended from 500 epochs in the previous simulations to 100,000 epochs. After the extensive training, an AoA effect was still observed. A. W. Ellis and Lambon Ralph argued that this provides evidence against the cumulative frequency hypothesis because the cumulative frequencies of the two sets of words were nearly equal at the end of training. In another simulation, the late trained patterns were presented at a higher frequency than the early trained patterns. The consequence of this is the late and early trained patterns had the same cumulative frequencies at the end of training. Despite this, the AoA effect still persisted, suggesting that AoA effects are not simply reducible to cumulative frequency.

Zevin and Seidenberg (2002) also attempted to model AoA effects in a connectionist framework. One difference between the two models is that A. W. Ellis and Lambon Ralph (2000) used training sets that were simply arbitrary bits with the output produced being a transformation of those bits. In Zevin and Seidenberg's (2002) model, real words were used as training sets in their simulations and the purpose of the model was to accurately "name" an orthographic input. Another difference was that Zevin and Seidenberg's (2002) model had four layers (a cleanup layer was involved in addition to input, output, and hidden units layers). In their first simulation, one set of words was trained more frequently in the beginning (early words) and one set was trained more frequently at the end (late words). Note, however, that the late items were still present in the first epoch of training, just at a lower frequency. This is in contrast to the type of training used by A. W. Ellis and Lambon Ralph. By the end of training, the two sets were equated on cumulative frequency. When the cumulative frequencies were the same for the two sets of words, Zevin and Seidenberg (2002) observed no difference between the early and late words.

In another simulation, Zevin and Seidenberg (2002) picked stimuli so that there was little orthographic or phonological overlap in the early and late words, which they argued would more closely mimic the design of A. W. Ellis and Lambon Ralph (2000). In this simulation, there was an advantage for early words over late words at the end of training when the cumulative frequencies for the sets of words were equated. However, they noted that this does not approximate what is observed in natural language. Another difference between the Zevin and Seidenberg (2002) simulations is that in their first simulation, where no AoA effect was observed, the early and late sets of words were trained with a large set of background words that had a constant frequency. This differs from A. W. Ellis and Lambon Ralph (2000) and also differs from how children learn language. In the simulation in which an AoA effect was observed (when there was little overlap between orthography and phonology), no constant frequency background words were used.[9]

The results from the two different articles modeling AoA effects in connectionist frameworks seem to contradict each other. The A. W. Ellis and Lambon Ralph (2000) results suggest that AoA is the important factor, as opposed to cumulative frequency. Alternatively, the results of Zevin and Seidenberg (2002) suggest that cumulative frequency is the most important factor involved. However, as Zevin and Seidenberg (2002) demonstrated, if there is no

[8] The cumulative frequency account of AoA was also recently incorporated into a nonconnectionist model of lexical search by W. S. Murray and Forster (2004). In this model, the lexicon is divided into a number of bins of words based on orthographic similarity. The bins are searched starting from top to bottom. The words are ordered in the bins by their rank frequency. This ranking could be based on cumulative frequency, which W. S. Murray and Forster suggested would account for AoA effects.

[9] I thank an anonymous reviewer for pointing this difference out.

overlap between the early and late learned sets (as in A. W. Ellis & Lambon Ralph's, 2000, simulations), then an AoA effect is observed. However, this is not the case in learning English, where there is significant overlap in the orthographies and phonologies of words learned early and late in childhood (Zevin & Seidenberg, 2002). Lambon Ralph and Ehsan (in press) recently performed another simulation using the connectionist model from A. W. Ellis and Lambon Ralph. However, they also manipulated the amount of overlap in the mappings between input and output. When the mapping was arbitrary (similar to picture naming), there were main effects of AoA and frequency and an interaction. When the mapping was quasi-consistent (where there is some overlap between input and output—similar to word naming), there was only a small but significant main effect of AoA.

Semantic Locus Hypothesis

Evidence against a semantic locus of AoA effects was provided by Morrison et al. (1992), who failed to find an effect of AoA in a task in which people had to categorize objects as either man-made or natural. This finding led many researchers to reject AoA as a semantic variable. However, there have recently been criticisms of the study by Morrison et al. (1992; e.g., Brysbaert, Van Wijnendaele, & De Deyne, 2000; Holmes & Ellis, in press), and as the review of object recognition experiments demonstrates, other researchers have been more successful in obtaining AoA effects in object recognition experiments (Holmes & Ellis, in press; Moore et al., 2004; Vitkovitch & Tyrrell, 1995).

The semantic locus hypothesis suggests that AoA effects should be observed in tasks that require access to semantic (conceptual) representations. To take the prediction a step further, AoA effects should be larger in tasks that involve semantic representations to a greater degree. This prediction was supported by the review, which showed the largest average AoA effect in picture naming (125 ms), followed by lexical decision (56 ms) and word naming (31 ms).

Other support for AoA's having a semantic locus comes from the fact that AoA effects have been observed in various semantic tasks. For example, Brysbaert, Van Wijnendaele, and De Deyne (2000) observed AoA effects in a word categorization task, where all early and late words were included in the same semantic category (words with definable meanings) and these words had to be discriminated from proper names (this finding was subsequently replicated by Ghyselinck, Lewis, & Brysbaert, 2004). Ghyselinck, Custers, and Brysbaert (2004) also recently found AoA effects in a semantic Simon paradigm. The eye movement study by Juhasz and Rayner (2003) also suggests that when cumulative frequency is accounted for, AoA is still a significant predictor of single-fixation durations (which they argued reflects access to word meaning).

Other evidence for a semantic locus of the AoA effect comes from experiments with patients. As mentioned previously, Gerhand and Barry (2000) found significantly more semantic errors that were early acquired in a patient with deep dyslexia. Likewise, Nickels and Howard (1995) found that although AoA did not predict phonological errors in a group of individuals with aphasia, it did significantly predict semantic errors.

Network Plasticity Hypothesis

According to the network plasticity hypothesis, patterns that are trained early in a network cause greater structural changes than later trained patterns, resulting in an advantage for earlier learned patterns and a gradual loss in plasticity (A. W. Ellis & Lambon Ralph, 2000). Empirical evidence was obtained by Nazir et al. (2003). They had children in Grades 1 to 5 perform lexical decisions on words they already had learned in the previous grades or words that were newly learned in their present grade. Examining the error rates, they observed that errors to newly learned material increased with increasing grade (i.e., older children had more difficulty with their newly learned words than did younger children). Also, performance on the words did not significantly improve in subsequent grades. For example, fifth graders made almost the same number of errors to the words that were newly acquired at each of the preceding grades as the children in those grades made, suggesting that those words were never learned as well.

As discussed previously, another aspect of the network plasticity hypothesis that has been borne out of simulation work with connectionist models is the mapping hypothesis, according to which AoA effects should be larger when the relationship between input and output is arbitrary (Lambon Ralph & Ehsan, in press; Monaghan & Ellis, 2002b; Zevin & Seidenberg, 2002). This is consistent with findings that AoA effects are larger in picture naming and lexical decision than in word naming. Direct empirical support for the mapping hypothesis was provided by Monaghan and Ellis (2002b), who found an interaction in English word naming between AoA and spelling-to-sound consistency, such that AoA effects were larger for words with inconsistent spelling-to-sound mappings. However, the relatively large AoA effect in Turkish (Raman, in press) is difficult for the mapping hypothesis to explain.

Lexical–Semantic Competition Hypothesis

Brysbaert and Ghyselinck (in press; see also Belke et al., 2005) suggested that there are two types of AoA effects: a frequency-related effect and a frequency-independent effect. They argued that the frequency-related AoA effect is observed in tasks such as word naming and lexical decision, where the size of the two effects is highly correlated and roughly equivalent. On the other hand, the frequency-independent AoA effect is observed in picture naming, word associate generation (Brysbaert, Van Wijnendaele, & De Deyne, 2000), and category-instance generation (Catling & Johnston, 2005). In the present review, the size of the correlations reported between the frequency and AoA effects were relatively small, amounting to .06 for naming (when delayed naming was not included) and .49 for lexical decision. Even though the correlations are relatively small, it is clear that in word naming there are small frequency and AoA effects, and in lexical decision there are somewhat larger effects of both variables, whereas in picture naming much larger AoA effects exist in the presence of small or reverse frequency effects. Thus, as Brysbaert and Ghyselinck (in press) suggested, there does appear to be something different about AoA effects in picture naming.

The lexical–semantic competition hypothesis was proposed by Belke et al. (2005) to explain this frequency-independent AoA

effect. According to Belke et al., competition arises when a lemma must be selected for a specific concept. Belke et al. supported this theory by showing larger semantic blocking effects for early acquired words compared with late acquired words, suggesting that the lemmas for early acquired words may be stronger competitors given a certain concept. Evidence against this theory could come from studies showing an effect of AoA in the absence of a frequency effect in a task that does not require lemma selection for a unique concept. As mentioned in the review of lexical decision experiments, Turner et al. (1998) observed a significant AoA (40 ms) and frequency effect (31 ms) of roughly the same size in visual lexical decision. However, in auditory lexical decision, they observed only a significant AoA effect (50 ms) in the absence of a significant frequency effect (−8 ms) for exactly the same stimuli. It is difficult to see how the lexical–semantic competition hypothesis could explain these results.

Conclusions and Future Directions

Although the correlations between the size of the AoA and frequency effects in word naming and lexical decision in the present review may not be terribly large, the observation that the AoA effect is much larger than the frequency effect in picture naming is supported (Brysbaert & Ghyselinck, in press). Therefore, the division of AoA effects into two classes, a frequency-related effect and a frequency-independent effect, may be useful. Belke et al. (2005) noted that the phonological completeness hypothesis is a theory that ascribes a special status to AoA effects over and above frequency and thus could be seen as a possible explanation for the frequency-independent effect. However, they ruled this theory out. The results from the present review agree with this conclusion. It should be clear from reading the evaluation of the phonological completeness hypothesis that experimental evidence does not support the phonological completeness hypothesis as a viable theory of AoA effects. For now, this leaves the lexical–semantic competition hypothesis as the remaining theory for the frequency-independent AoA effect in picture naming.[10]

However, the lexical–semantic competition hypothesis does not explain what is causing the smaller effect of AoA seen in other tasks such as word naming, lexical decision, object recognition, and eye fixation durations (among others). Simply because the AoA effect reported in these tasks is usually of the same magnitude as the frequency effect does not imply that the AoA effect is unimportant. Three possible explanations for this effect were outlined earlier, the cumulative frequency hypothesis, the semantic locus hypothesis, and the network plasticity hypothesis.

Perhaps the most parsimonious explanation would localize both the AoA and frequency effects in these tasks as cumulative frequency effects. However, as discussed in the evaluation of this theory, AoA cannot simply be reduced to cumulative frequency. This is not to say that cumulative frequency is not an important variable in and of itself. In fact, one could argue that there are three variables that are important to consider when discussing lexical processing: when a word was first learned (AoA), the number of encounters with the word over a life span (cumulative frequency), and the number of encounters with the word in the recent past (adult frequency). It is an interesting question for future research whether the effects of cumulative frequency and adult frequency can be teased apart. Is there an effect of adult frequency over and above cumulative frequency? Conversely, perhaps adult frequency is more important than cumulative frequency, with recent encounters being the most important factor in word recognition.

The discussion of AoA, cumulative frequency, and adult frequency is relevant to a study recently reported by Zevin and Seidenberg (2004). They suggested that frequency trajectory, as opposed to rated or objective measures of AoA, may be a better variable to use in studying what they refer to as *age-limited learning*, because it is less highly correlated with other psycholinguistic variables. Frequency trajectory is measured in the Zeno et al. (1995) norms. By examining the frequency information for differing grade levels, one can find words with high frequency for early grade levels compared with later grade levels as well as words with a higher frequency for later grade levels compared with early grade levels. Zevin and Seidenberg (2004) referred to the items with high-to-low frequency trajectories as *early learned words* and the items with low-to-high frequency trajectories as *later learned items*. In an experiment, they orthogonally manipulated both the frequency trajectory and the cumulative frequency of items in a word naming task. Although they observed a significant effect of cumulative frequency, frequency trajectory was not significant, which they interpreted as evidence against AoA effects in word naming tasks. However, on examining the stimuli used by Zevin and Seidenberg (available on the Internet[11]), it became obvious that there is a problem with using frequency trajectory as a proxy for AoA. Specifically, items with a high-to-low frequency trajectory that were considered early items in the Zevin and Seidenberg (2004) article have a significantly lower adult frequency than items with a low-to-high frequency trajectory. This difference in adult frequency is significant for words with a high cumulative frequency ("early words" = 67; "late words" = 141), $t(54) = -2.34$, $p = .023$, and words with a low cumulative frequency ("early words" = 3; "late words" = 10), $t(54) = 4.85$, $p < .001$.[12] This difference in adult frequency is most likely not due simply to a failure to control for adult frequency but is inherent in the definition of frequency trajectory itself. By definition, a word with a high-to-low frequency trajectory should have a lower adult frequency than a word with a low-to-high frequency trajectory. Thus, although frequency trajectory is an interesting variable and is less correlated with other variables than AoA, it is not the best way to study true AoA effects.

Although the research discussed in the Evaluation of AoA Theories section suggests that AoA effects are not merely cumulative frequency effects, the majority of studies have not controlled for cumulative frequency. This point was highlighted by Zevin and Seidenberg (2002) and may be one reason why many influential researchers have continued to dismiss AoA effects. Therefore, it is

[10] Actually, Belke et al. (2005) also suggested the semantic locus as a possible locus of the frequency-independent AoA effect but ruled it out. Here, it is considered to be a possible locus of the frequency-related effect because Steyvers and Tenenbaum (2005) suggested a similar effect of both AoA and frequency in a semantic network.

[11] The webpage provided by Zevin and Seidenberg (2004) for their materials is http://lcnl.wisc.edu/people/jdzevin/zsappendix.html

[12] These adult frequencies are based on Francis and Kucera (1982) for most items. When these were unavailable, CELEX frequencies per million (Baayen et al., 1995) were substituted.

important for researchers interested in studying true AoA effects to control for both cumulative frequency and adult frequency using the most up-to-date frequency sources available. Some measures of adult frequency, such as Kucera and Francis (1967; Francis & Kucera, 1982) frequency (in the case of English) are based on a small number of samples and are most likely out of date. Larger, more recent corpora such as CELEX (Baayen et al., 1995) are preferable. In addition, cumulative frequency should also be controlled across AoA levels. This can be accomplished in English by using the sum of the frequencies for different grade levels in the Zeno et al. (1995) WFG frequency norms. Of course, there are languages other than English for which published cumulative frequency norms may not exist. Some researchers have suggested that familiarity can be thought of as a type of cumulative frequency measure (e.g., Ghyselinck, Lewis, & Brysbaert, 2004; Moore & Valentine, 1998). Therefore, when more objective cumulative frequency norms are not available, researchers should use a familiarity–subjective frequency norming procedure in which the instructions stress the importance of rating items for how often the person has come in contact with the word throughout his or her lifetime.

Because the cumulative frequency hypothesis can be ruled out as a reason for AoA effects, the remaining choices are the network plasticity hypothesis and the semantic locus hypothesis. One may wonder why the semantic locus hypothesis is kept as a separate alternative, as the network plasticity hypothesis predicts AoA effects in semantic tasks as well. One difference between the two hypotheses is that according to a strong interpretation of the semantic locus hypothesis AoA effects should be observed only in tasks requiring some access to semantics. One way to test between these theories, then, is to test whether AoA effects can be found in a task that requires no access to semantics if such a task exists.

In support of multiple loci for AoA effects, factor analyses suggest that AoA may be related to multiple underlying factors. Bates et al. (2001) found that two subjective measures of AoA loaded heavily on both a frequency factor and a semantic factor. A measure of objective AoA loaded only on the semantic factor, however. Consistent with the mapping hypothesis, this semantic factor predicted picture naming performance, but not word naming performance in Italian. Likewise, Rubin (1980) found that a rated AoA variable loaded about equally heavily on three different factors. These were the spelling and sound factor, the imagery and meaning factor, and the word frequency factor. Both of these studies suggest that AoA may affect word recognition studies through several different channels (which is consistent with the network plasticity hypothesis).

Another reason to keep the network plasticity hypothesis and the semantic locus hypothesis separate is that the network plasticity hypothesis is based on simulations from the connectionist model of A. W. Ellis and Lambon Ralph (2000), which used distributed representations. Although connectionist models have been very popular in cognitive science, there are some who have argued against the validity of distributed representations (e.g., Bowers, 2002; Brysbaert & Ghyselinck, in press) for language processes. The model of Steyvers and Tenenbaum (2005) provides an alternative model of AoA effects in a semantic network that does not use distributed representations. In the Steyvers and Tenenbaum model, earlier learned words have more connections to other concepts than later learned words, as do higher frequency words. Lexical search is biased toward more highly connected words, resulting in an advantage for both early acquired words and high-frequency words. In this semantic network, meaning is defined not in the node containing the concept itself but in the pattern of connectivity for that node. One difference between this approach and the network plasticity hypothesis is that they conceptualize the process resulting in AoA effects differently (Steyvers & Tenenbaum, 2005). In the network plasticity account, late acquired words have a disadvantage because they are not encoded as well as early acquired words, because of a loss in network plasticity. In the Steyvers and Tenenbaum model, both early and late acquired words are encoded to an equal degree; what differs is the number of connections to other concepts. Because the number of connections is reasoned to affect lexical search, the difference between early and late AoA words lies in differences in retrieval. It is interesting to note that the semantic network of Steyvers and Tenenbaum (2005) is similar to the way Levelt et al. (1999) discussed the concept level in their word production model. Thus, this model can fit very nicely with the theory of Belke et al. (2005), where the frequency-related AoA effect is localized at the conceptual level, by the number of connections, and the frequency-independent AoA effect is localized at the links between the conceptual and lemma level.

In summary, the results from the many studies discussed in this review provide strong evidence that the AoA effect is a very real phenomenon that generalizes to many different tasks, languages, types of stimuli, and participant populations. It also appears to be just as strong as (or stronger than) the often-discussed word frequency effect. This fact may call into question many of the models of word recognition that incorporate word frequency but fail to incorporate AoA. In fact, based on the review, it appears that AoA, cumulative word frequency, and adult word frequency may all influence lexical processing. At this point in time, the exact locus of the AoA effect is still uncertain. However, it is obvious that AoA influences semantic processing. This effect of AoA on semantic processing can be viewed in terms of either encoding differences between early and late acquired words (e.g., A. W. Ellis & Lambon Ralph, 2000) or differences in retrieval (Steyvers & Tenenbaum, 2005). Future research is needed to clarify these positions.

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