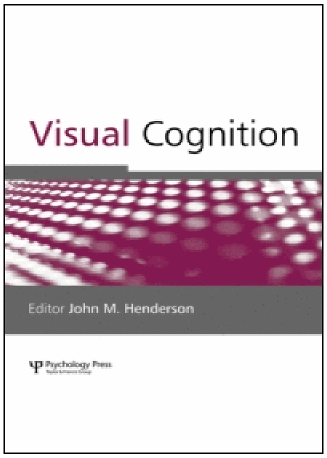

Visual Cognition

Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713683696

Age of acquisition effects depend on the mapping between representations and the frequency of occurrence: Empirical and computational evidence

Matthew A. Lambon Ralph [a]; Sheeba Ehsan [a]
[a] University of Manchester, UK

Online Publication Date: 01 May 2006
To cite this Article: Ralph, Matthew A. Lambon and Ehsan, Sheeba (2006) 'Age of acquisition effects depend on the mapping between representations and the frequency of occurrence: Empirical and computational evidence ', Visual Cognition, 13:7, 928 - 948
To link to this article: DOI: 10.1080/13506280544000110
URL: http://dx.doi.org/10.1080/13506280544000110

VISUAL COGNITION, 2006, 13 (7/8), 928–948

Psychology Press
Taylor & Francis Group

Age of acquisition effects depend on the mapping between representations and the frequency of occurrence: Empirical and computational evidence

Matthew A. Lambon Ralph and Sheeba Ehsan
University of Manchester, UK

In the last few years, a number of connectionist models have been described that provide an explanation for age-of-acquisition (AoA) effects in verbal and nonverbal tasks. Further simulations and an empirical study were conducted to test two predictions that arise from these models. The first prediction is that AoA effects will be modulated by the nature of the mapping between representations; effects should be largest for arbitrary mappings (i.e., where there is no relationship between input and output representations such as that found in mapping semantics to phonology, e.g., picture naming), smaller for systematic mappings and minimal for componential representations (such as those found in mapping orthography to phonology for languages with relatively transparent orthographies). The second prediction from the models is that not only AoA but also frequency should influence performance and that these two variables might interact. These two predictions were tested in an empirical study. Performance on a set of 80 picturable nouns that orthogonally varied AoA and word frequency was directly compared in picture and word naming experiments. As predicted, there was a dramatic interaction between AoA and task, with substantial AoA effects in picture naming but not word naming. In addition, there was evidence for an interaction between AoA and frequency in both tasks. These results highlight the importance of the computational mapping between representations when considering both the likely performance in any task and the influence of any underlying factors.

Although it is possible to trace consideration of age-of-acquisition (AoA) effects (better performance for early than late acquired items) back to early aphasiological studies (Freud, 1891/1935), there were few empirical investigations of this variable until the study of Carroll and White (1973). Since then, and especially in the last decade, there have been an increasing number of

---

Please address all correspondence to Prof. M. A. Lambon Ralph, School of Psychological Sciences, University of Manchester, Oxford Road, Manchester M13 9PL, UK.
Email: matt.lambon-ralph@manchester.ac.uk

We thank Mark Seidenberg and Jay McClelland for helpful conversations about the issues discussed in this paper.

http://www.psypress.com/viscog DOI: 10.1080/13506280544000110

investigations that have highlighted the potential importance of AoA on task performance. Initial studies were conducted primarily by language researchers. These studies reported AoA effects in a range of lexical tasks including word naming, picture naming, and written and auditory lexical decision (Barry, Morrison, & Ellis, 1997; Ellis & Morrison, 1998; Gerhand & Barry, 1998, 1999; Morrison & Ellis, 1995; Turner, Valentine, & Ellis, 1998). In addition, AoA has been found to predict the likelihood of naming in a range of aphasic patients with acute or progressive brain injury (Cuetos, Aguado, Izura, & Ellis, 2002; Ellis, Lum, & Lambon Ralph, 1996; Hirsh & Ellis, 1994; Lambon Ralph, Graham, Ellis, & Hodges, 1998; Nickels & Howard, 1995). Although some doubts were expressed about the early investigations because they relied on adult estimates of AoA, more recent studies have collected objective measures of AoA (Morrison, Chappell, & Ellis, 1997) and have replicated the initial findings (Ellis & Morrison, 1998).

As with many other psycholinguistic variables (e.g., Monsell, 1991), a principal goal of these studies was to identify the locus of AoA. Initial reports had identified AoA effects in a whole range of receptive and expressive language tasks but not in object semantic categorization (Morrison et al., 1997). This led to the conclusion that AoA must be in a post-semantic aspect of speech production and in a locus that is tapped by word naming and lexical decision tasks. Morrison et al. had also demonstrated that AoA effects were not found in a delayed naming task in which subjects were able to prepare their utterance in advance of a signal to articulate. They concluded, therefore, that the locus of AoA was in the phonological representations themselves rather than any other aspect of speech production. However, more recent studies of nonverbal tasks have suggested that the influence of AoA might be more pervasive than originally thought. Object and face recognition (familiarity judgements) have been found to be influenced by AoA (Moore & Valentine, 1999; Vitkovitch & Tyrrell, 1995). Similar effects have also been reported for semantic tasks (Brysbaert, van Wijnendaele, & de Deyne, 2000; Lewis, 1999). There are indications that AoA-like effects can be found in nonhuman species and may also be related to critical period effects (Zevin, Seidenberg, & Bottjer, 2004). For example, in a seminal paper from the errorless learning literature, Terrace (1963) demonstrated that pigeons' ability to learn a red–green visual discrimination was influenced by the presence of errorful responses by the birds: Learning was much more effective when the pigeons were prevented from making errors. In one experiment, Terrace manipulated the training period during which errorful responses were prevented. In a direct comparison between early and late phases of errors, Terrace found that learning was better if the early period was error free. The notion of reduced learning later in life may also be related to critical periods; that is to say, an extreme version of AoA effects would resemble the closing of a critical period—effective early learning followed by gradually poorer learning until the acquisition of new information stops. Critical period effects are, of course, found in a whole range of cognitive domains in human and nonhuman species, suggesting that they are underpinned by a generic property of any learning system or the underlying neural mechanisms (Ellis & Lambon Ralph, 2000; Munro, 1986; Zevin & Seidenberg, 2002; Zevin et al., 2004).

At face value, the fact that representations learned early are processed more efficiently than those acquired later in life seems counterintuitive. Indeed, until very recently, there were very few theoretical explanations for AoA. Gilhooly and Watson (1981) suggested that AoA was reflected directly in the unit thresholds of a logogen model (Morton, 1969) but gave little explanation of how such thresholds come to be set during learning. Brown and Watson (1987) argued that AoA effects reflect the impact of limited resources within the lexicon; while early acquired items may be stored whole, the representations of later acquired items have to be more fragmentary if the large adult vocabulary is to be incorporated into a lexicon with limited capacity. The time costs associated with late acquired words reflect, therefore, the extra processing required to amalgamate the fragments into a coherent form. Again, there was no computational description for the gradual fragmentation of representations as words are learned, nor any explanation of how these fragments are linked and reformed during lexical access/retrieval. To be fair, though, it should be noted that the general notion of AoA reflecting limited representational capacity has been tested and supported in computational explorations with a Kohonen network (Morrison, 1993). In addition, this proposal had never been tested empirically until very recently. Monaghan and Ellis (2002a) tested the hypothesis by asking subjects to complete a phonological segmentation task for early and late acquired words. Brown and Watson's phonological completeness hypothesis predicts that it should be harder to segment early acquired words because they are stored whole. Monaghan and Ellis found little evidence to support this notion and, in fact, when required to segment a phoneme from a consonant cluster, subjects were actually faster for early acquired items.

The counterintuitive nature of AoA was reinforced by a computational phenomenon in connectionist modelling known as catastrophic interference (e.g., McCloskey & Cohen, 1989). This refers to the fact that the act of learning a second set of representations interferes with, or "overwrites", the information about the first group of items. This computational phenomenon led to the suggestion that AoA effects were intrinsically incompatible with connectionist models of human behaviour (e.g., Gerhand & Barry, 1998; Moore & Valentine, 1998; Morrison & Ellis, 1995). McClelland, McNaughton, and O'Reilly (1995) demonstrated, however, that catastrophic interference only occurs if the two sets of representations are completely separated (focused learning). In contrast, information about the first set of representations is unaffected by later learning of a second group of items if the first set continues to be presented to the network (interleaved learning). Ellis and Lambon Ralph (2000) used this fact as the basis to explore AoA effects in a connectionist model. They argued that language learning is fundamentally cumulative in nature such that early acquired items continue to be experienced while other words are learned. Using cumulative learning in a simple, three-layer, feedforward network, Ellis and Lambon Ralph found that even relatively small differences in the order of entry led to long-term, stable differences in how well early and late patterns were represented—i.e., the model demonstrated AoA effects (see also Zevin & Seidenberg, 2002).

Perhaps more importantly, analyses of the network revealed that AoA effects arose from a generic aspect of learning; as learning proceeds in such models, the remaining plasticity of the network reduces (Munro, 1986). This automatically means that the point during learning at which items are first encountered will have a long-term and stable effect on the eventual learning outcome. Early acquired representations benefit from that fact that the system is at its most plastic at the beginning of learning. The link to the more general notion of plasticity adds to the idea that AoA and critical period effects are intimately related—in effect they are points on a plasticity continuum. If plasticity reduces completely during learning, then a critical period effect is produced. On the other hand, if plasticity only partially reduces, items that are encountered late during training can still be learned but not as effectively as early acquired items (an AoA effect). In addition, the notion that AoA effects might reflect a general characteristic of learning is also consistent with the fact that AoA effects have been found for verbal and nonverbal tasks in humans, and AoA-like phenomena have been described for nonhuman species.

Zevin and Seidenberg (2002) used a parallel set of simulations to demonstrate an important caveat to the idea that AoA effects should be found in all tasks. Specifically, they noted that the mapping between the representations used by Ellis and Lambon Ralph (quasisystematic; 2000) was not characteristic of the relationship between orthography and phonology in English (which is componential in nature; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989). Using a large simulation of single-word reading, Zevin and Seidenberg showed that there was little or no AoA effect but it could be reproduced if the input–output representations were altered so that they had no overlap. The lack of an AoA effect in the reading simulations follows directly from the fact that componential representations allow the model, and the human reading system, to generalize to new orthographic patterns. Having learnt to transform CAT and DOG into the appropriate phonological representations, it takes little or no additional learning to read COG, COT, DOT, etc., because the phonological realization for each letter/grapheme remains unchanged from one word to the next (at least for words with consistent spelling-to-sound correspondences). This means that late acquired words will not suffer from reduced plasticity because little additional learning is required for the reading system to pronounce them correctly. Indeed, we know that the reading system can generalize very well even to completely novel forms (nonwords), which are, by definition, like very late acquired words.

The status of AoA effects in word naming experiments is unclear and has lead to a recent debate (Ellis & Monaghan, 2002; Monaghan & Ellis, 2002b; Strain, Patterson, & Seidenberg, 2002). As noted above, some studies have found relatively small but significant effects of AoA in word naming. Others have argued that these have resulted from poorly controlled sets of stimuli or other methodological factors (Zevin & Seidenberg, 2002). An extension of the original simulations conducted by Ellis and Lambon Ralph (reported in Monaghan & Ellis, 2002b) also found that there was little or no effect of AoA on words with consistent spelling-to-sound correspondences but that there was a small AoA effect for words with inconsistent elements (e.g., PINT). This was especially true of low frequency patterns. Although they did not investigate words with inconsistent spelling-to-sound correspondences, Zevin and Seidenberg did look at "strange" words (those with a rime-body pronunciation that is not shared by other words, e.g., PHLEGM). They found that, even with these strange words, there was no AoA effect and noted that these words also benefit from generalization. Thus, the status of AoA effects in simulations of reading, like the empirical studies, remains unclear. AoA effects might occur for inconsistent rather than strange words because the correct pronunciation of the inconsistent element (most commonly the vowel), by definition, runs counter to all the other words in its body cohort. This means that a small amount of item-specific learning will be required for these words. In such circumstances, AoA effects (as well as frequency effects) should follow albeit small in magnitude because most of the letters within inconsistent words are actually consistent (for example, it is only the "i" in PINT that is inconsistent).

Although this small aspect of the two models is open to debate, they agree on two fundamental points, which were explored in the present study. First, by comparing across simulations (Ellis & Lambon Ralph, 2000; Monaghan & Ellis, 2002b; Zevin & Seidenberg, 2002), it would appear that the size of the AoA effect varies as a function of the mapping between representations. AoA effects are larger for arbitrary and systematic representations but small or, perhaps, nonexistent for componential representations. If one compares the AoA effects found in picture versus word naming studies, then this difference appears to hold (AoA effects are typically an order of magnitude larger for picture naming). Direct contrasts are hampered, however, by the fact that these comparisons can only be made across different studies and sets of items. The purpose of the current study was to compare, therefore, the AoA effects more directly for these two tasks—both in simulations using the same architecture and in an empirical study that used the same items for picture and word naming.

Secondly, the two simulations also suggest that both AoA and frequency should influence performance, either as two main effects or in the form of an interaction (see Ellis & Lambon Ralph, 2000, simulation 11). Again, the empirical literature contains mixed results. Some of the first studies of picture and word naming found that no frequency effect remained once AoA was controlled (e.g., Carroll & White, 1973; Morrison, Ellis, & Quinlan, 1992). More recent studies, using objective AoA norms and better frequency measures, have typically found influences of both variables on performance (e.g., Gerhand & Barry, 1998, 1999). There is a paucity of data on the question of whether AoA and frequency interact. This is, at least in part, due to the methodology used. A number of studies have not fully crossed the two factors but rather have manipulated one while holding the other constant (e.g., Morrison & Ellis, 1995; Morrison et al., 1992). Likewise, most regression-based experiments have entered many, if not all, of the relevant psycholinguistic variables into the equations but have not included any interactive terms. However, three studies by Barry and colleagues have investigated this issue. In the first (Barry et al., 1997), a regression-based analysis found evidence for a significant interaction between the two variables in a picture naming study. The second word naming experiment used a parametric design to cross the two factors but found no interaction (Gerhand & Barry, 1998). The same materials did produce an interaction, however, in a speeded naming experiment—with larger frequency effects for late acquired words (Gerhand & Barry, 1999).

COMPUTATIONAL MODEL

Results from the various simulations in the literature suggest that the size of any AoA effect should vary according to the nature of the mapping between input and output representations (Zevin & Seidenberg, 2002). This was explored directly by testing a full range of mapping types within the same architecture (the same network as that used by Ellis & Lambon Ralph, 2000). These included completely arbitrary mappings (analogous to the mapping between semantics and phonology for picture names), systematic and quasisystematic mappings (the same used in the Ellis and Lambon Ralph study) and quasiconsistent, componential mappings (to produce a domain like reading). The difference between systematic and quasiconsistent mappings is that there is a clear, predictable relationship between input and output representations for systematic mappings but that the representational pairs are different from each other. In contrast, elements within componential, quasiconsistent representations are repeated across items (just like letters and phonemes). To explore the influence of AoA and frequency effects for each of these mapping types, the order of entry (AoA) and the number of presentations per epoch (frequency) were manipulated.

Method

The simulations used the same network architecture and parameters as Ellis and Lambon Ralph (2000). A brief summary of the key details is given here. All simulations used a simple three-layer feedforward network trained with standard back propagation without momentum (for a total of 5000 epochs). The input and output layers contained 100 units, each fully connected to 50 intermediate, hidden units. For the arbitrary mappings, 200 input patterns were randomly generated (with a probability of .2 of any specific unit being on). The output representations were produced in the same way, leading to arbitrarily related input and output pairs. For the systematic mappings, the same process was used to generate the input representations but these patterns were also used for the corresponding output representations (i.e., the model was an autoassociator). For quasisystematic representations, a mild degree of perturbation was applied to the input pattern to produce the output representation (bit values were flipped with a probability of .1). The quasiconsistent (componential) representations were created in the following way. The 100 units were split into three sections (33, 34, 33) and each was used to represent a CVC-like word. Abstract patterns for 10 consonant and 10 vowel components were generated in the same way as for the other mapping types (each unit was turned on with a probability of .2). Two hundred representations were formed by joining the CVC patterns using a Latin-square type combination. This ensured that all 10 consonant (used in both onset and offset positions) and vowel patterns were used 20 times each. To mimic words with consistent spelling-to-sound correspondences, the input and output representations were identical. For 40 of the pattern pairs, however, the consonant patterns were identical at input and output but the model had to produce a different vowel pattern on the output layer (one of the other nine possible vowel patterns). This mirrors the fact that many words with inconsistent spelling-to-sound correspondences have an inconsistent vowel but consistent consonants.

AoA and frequency were implemented in the same way for all three types of mapping. One half of the patterns were included in the training set from the beginning (early patterns) and the remaining representations were added to the training set after 750 epochs of training (late patterns). Most patterns were presented to the model only once per epoch (low frequency) but 25% were presented 10 times every epoch (high frequency).

Results

As predicted, the size of the AoA effect varied considerably across the four mapping types (see Figure 1). A 2 (AoA) × 4 (mapping types) ANOVA confirmed main effects of AoA, $F(1, 792) = 416.3$, $p < .001$, mapping type, $F(3, 792) = 184.4$, $p < .001$, and a significant interaction, $F(3, 792) = 70.3$, $p < .001$. For the quasiconsistent mappings, the very small AoA difference was still statistically reliable due to the number of training patterns used, $t(198) = 3.2$, $p = .002$.

For a more direct comparison with the empirical study (see below), a detailed analysis of the simulations with arbitrary and quasiconsistent mappings was conducted. These are closest to the type of mappings found in the two experimental tasks (picture and word naming, respectively). The overall performance for the two simulations is shown in Figure 2. A 2 (AoA) × 2 (frequency) × 2 (mapping type) ANOVA revealed that there was an interaction between AoA and frequency, $F(1, 392) = 3.78$, $p = .05$, between AoA and mapping type, $F(1, 392) = 112.8$, $p < .001$, and between frequency and mapping type, $F(1, 392) = 60.7$, $p < .001$. Furthermore, the three-way interaction was also significant, $F(1, 392) = 7.34$, $p = .007$. Considering the arbitrary (pseudo picture naming) simulation alone, there were both main effects of each variable and a significant interaction, which resulted from a greater frequency effect for the late acquired items: AoA, $F(1, 196) = 172.7$, $p < .001$; frequency, $F(1, 196) = 70.6$, $p < .001$; interaction, $F(1, 196) = 6.5$, $p = .01$. For the quasiconsistent (pseudo reading) model, only the main effect of AoA was reliable, $F(1, 192) = 10.5$, $p = .001$.

Summary

As suggested by the simulations included in the AoA literature, the size of the AoA effect varied considerably for different mapping types (see also Zevin & Seidenberg, 2002). AoA effects were greatest for the arbitrary mappings, intermediate for systematic and then quasisystematic mappings, and very small for the quasiconsistent mappings. As noted by Zevin and Seidenberg in a reading simulation with a much larger sample of training patterns, this small AoA effect might even reduce to zero because the ability of the network to extract knowledge about the consistency of the reading domain depends on how many examples are used during training. The arbitrary and quasiconsistent mappings are of most interest for comparison with the tasks included in the empirical investigation (analogous to picture and word naming, respectively). As predicted both AoA and frequency effects were most pronounced for the arbitrary (pseudo picture naming) mappings and very small for the quasiconsistent (pseudo reading) mappings.

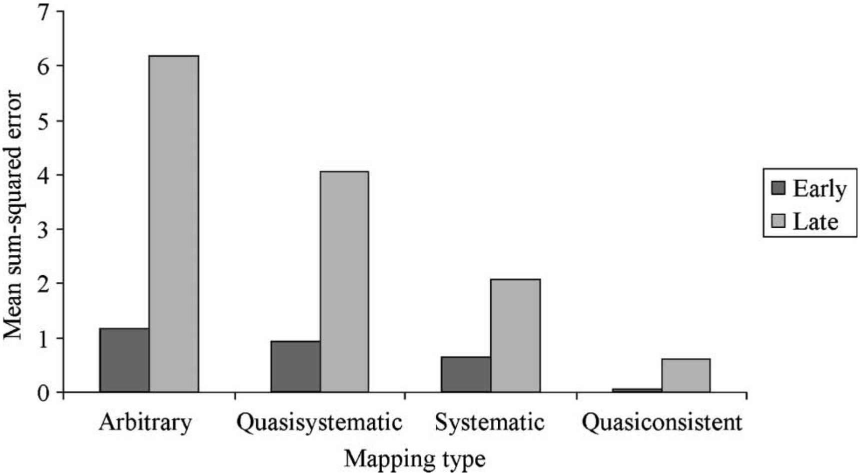

Figure 1. Modulation of the AoA effect for four mapping types.

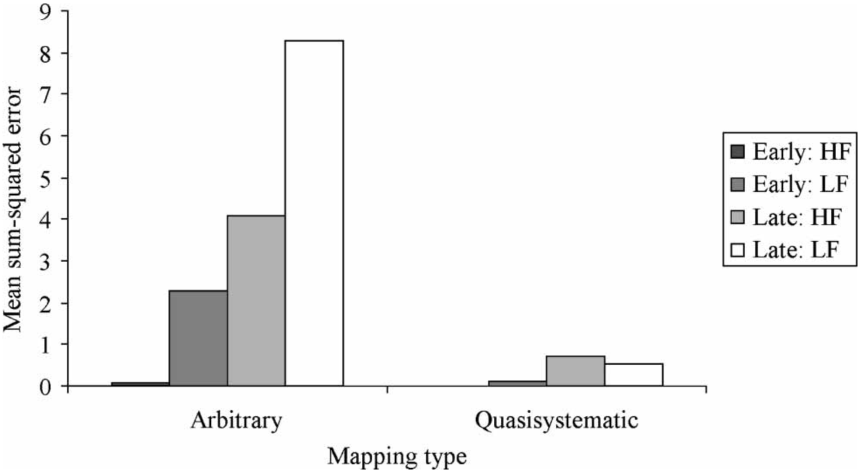

Figure 2. Variation in the frequency and AoA effects for arbitrary and quasiconsistent mappings.

AoA and frequency were found to interact overall, though this was only reliable for the arbitrary mappings simulation.

EMPIRICAL STUDY

The findings from these simple simulations were compared directly against human empirical data. Specifically, for the same set of 80 picturable nouns, two groups of participants were asked either to name these items when presented as pictures or to read their written names aloud. AoA and word frequency were orthogonally varied across these 80 items. Given that the principal aim was to investigate the AoA and frequency effects across these two tasks, a direct (repeated items) comparison was achieved by using the same items in the two experiments. This meant that the two groups had to produce the same spoken output in both experiments but had to do so either from picture/semantic representations (an arbitrary mapping) or orthographic input (a quasiconsistent mapping). Unfortunately, the constraints for this experimental design (picturable nouns varying AoA and frequency) do not allow the written words to be varied, or selected, for the consistency of their spelling-to-sound correspondences. As noted in the Introduction, the only simulations for which a clear, albeit small, AoA effect on word naming has been noted are those that include low frequency, inconsistent words (Monaghan & Ellis, 2002b).

Method

Materials. Items were selected from the objective AoA corpus (Morrison et al., 1997). The psycholinguistic values for these nouns were also taken from the same database. In order to match properties for the AoA × Frequency manipulation, 20 quartets were selected from the corpus. Each quartet orthogonally varied objective AoA (75% rule) and combined Celex frequency in such a way that the low and high frequency pairs were matched for AoA and the early and late pairs were matched for frequency. In addition, each quartet was matched for visual complexity, name agreement (only items with high name agreement were selected), and letter length. Phoneme and syllable length were also matched as closely as possible. The resultant set of 80 experimental items is shown in the Appendix, along with the corresponding psycholinguistic properties. Ten additional practice items were also selected.

Participants and procedure. Forty-four psychology undergraduates from the University of Manchester agreed to take part in the experiment as a part of their course requirement. Half of them were randomly sorted into the word naming experiment and the remainder completed the picture naming experiment. In the word naming experiment, the name of each item was written in lower case. Line drawings were used in the picture naming experiment (selected from two sources: Morrison et al., 1997; Snodgrass & Vanderwart, 1980). Stimuli were presented to the participants in the same way for each experiment. Each trial commenced with a "Ready?" signal and a key press by the experimenter. This was followed by a fixation cross presented in the centre of the screen for 250 ms, a blank screen for 250 ms and then the target stimulus (word or picture). This remained on the screen until the subject triggered a voice key by saying the name of the target item. The particpants' responses were recorded by the experimenter after each trial. The order of presentation was randomized across participants and the experimental items were preceded by 10 practice items. The participants were asked either to read the words aloud or say the name of the picture as quickly and accurately as they could. They were discouraged from making any other verbal responses such as 'um', 'err', etc. before saying the name of the stimulus.

Data analysis. Reaction times were removed and treated as missing data if the subject had produced an error/false start or if the times were excessively short or long (greater than three standard deviations for the relevant condition). For the word naming experiment, only 3 reaction times were removed for errorful responses and 11 for excessively short/long times. For picture naming, a total of 80 items were removed because of errors and 14 for short/long response times. Given the very low error rate for both experiments, only the reaction times were submitted to statistical analysis.

Results

The by-subjects and by-items reaction times were entered into a 2 (AoA) × 2 (frequency) × 2 (task) ANOVA. Unless otherwise stated all values were $p < .01$. All three main effects were significant: AoA, $F1(1, 42) = 110.7$, $F2(1, 76) = 29.5$; frequency, $F1(1, 42) = 9.24$, $F2(1, 76) = 3.01$, $p = .09$; task, $F1(1, 42) = 41.0$, $F2(1, 76) = 611.3$. As predicted (see Figure 3), the AoA

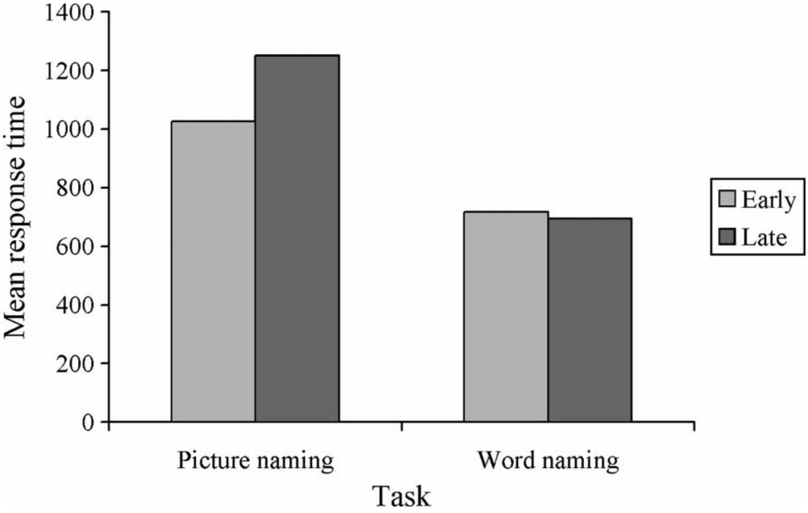

Figure 3. Variation in the AoA effect for picture and word naming.

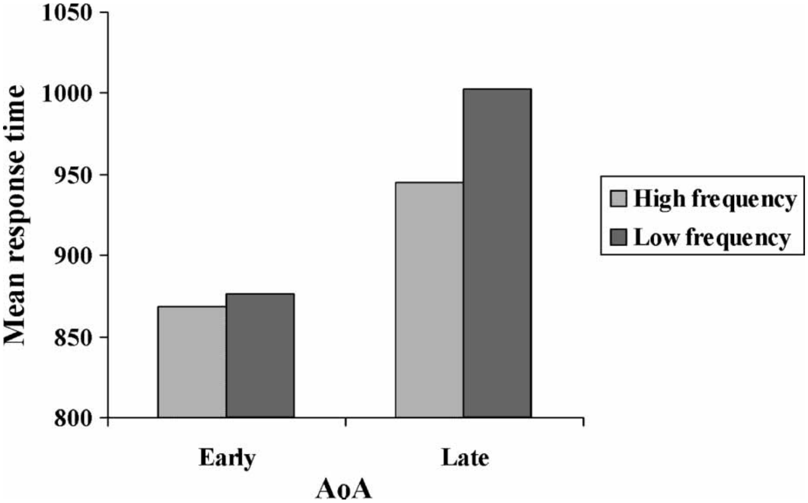

Figure 4. Interaction between AoA and frequency (collapsed across task).

effect interacted strongly with task, *F1*(1, 42) = 168.4, *F2*(1, 76) = 48.1. Post hoc *t*-tests conducted on the by-items and by-subjects data confirmed that picture naming times were significantly faster for early than late acquired words, *t1*(21) – 13.5; *t2*(78) = 6.33, but the small difference in mean reading times favouring late acquired items was not statistically reliable, *t1*(21) = 2.49, $p = .02$; *t2*(78) = 0.71, n.s. There was a borderline interaction between AoA and frequency, *F1*(1, 42) = 4.85, $p = .03$; *F2*(1, 76) = 2.46, $p = .12$, but there was little evidence that this interacted, in turn, with task: AoA × Frequency × Task, *F1*(1, 42) < 1; *F2*(1, 76) < 1. The form of the interaction between AoA and frequency is shown in Figure 4. Post hoc *t*-tests confirmed that this was due to a frequency effect for late acquired words, *t1*(43) = 3.58; *t2*(38) = 1.93, $p = .06$, but not for the early acquired items, *t1*(43) = 0.54, n.s.; *t*2(38) = 0.16, n.s. Finally, there was some weak evidence for an interaction between frequency and task, *F1*(1, 42) = 3.23, *p = .08; F2*(1 ,76) < 1.

Summary

Most of the predictions that arose from the computational simulations (both those reported here and those found in the existing literature: Ellis & Lambon Ralph, 2000; Monaghan & Ellis, 2002b; Zevin & Seidenberg, 2002) were upheld in this empirical study. As predicted there was a strong interaction between AoA and task. There was a substantial AoA effect for picture naming (a 226 ms difference, 20% of the global mean picture naming time) but no difference in word naming. In addition, there was an effect of frequency on response times with some evidence to suggest that this effect was smaller for word than picture naming. There was also a modest interaction between these two variables such that frequency effects were most pronounced for late acquired words. Although the simulations reported in this study found a three-way interaction between AoA, frequency, and task, no evidence was found for this in the empirical study. It should be noted, however, that previous simulation studies have shown that the presence or absence of an interaction between AoA and frequency is entirely dependent on the degree to which each variable is manipulated (see Ellis & Lambon Ralph, 2000, simulation 11).

GENERAL DISCUSSION

Previous connectionist theories have attempted to explain age of acquisition effects in terms of age-dependent reductions in plasticity (Ellis & Lambon Ralph, 2000; Zevin & Seidenberg, 2002). While these theories may be useful simply because of the paucity of theoretical accounts in the AoA literature, the potential link with a general characteristic of learning mechanisms (plasticity) places AoA effects on a much broader theoretical canvas. It is then possible to think about a range of phenomena in human and nonhuman subjects including critical periods, second-language learning and AoA, all in terms of plasticity-related effects (Ellis & Lambon Ralph, 2000; Munro, 1986; Zevin & Seidenberg, 2002; Zevin et al., 2004). Ellis and Lambon Ralph (2000) argued that the link between AoA and plasticity meant that, given the correct measures, AoA effects should be found across all tasks. Consistent with this prediction, more recent investigations have reported AoA effects in nonverbal as well as verbal tasks such as object and face familiarity judgement and semantic categorization (Lewis, 1999; Moore & Valentine, 1999; Vitkovitch & Tyrrell, 1995). In addition, it is also possible to find AoA-like phenomena in nonhuman species (e.g., Terrace, 1963).

Zevin and Seidenberg (2002) demonstrated an important caveat to this hypothesis, namely that AoA effects should be dependent on the nature of the mapping between representations. While AoA effects should emerge for tasks requiring an arbitrary mapping (e.g., picture naming), there should be little or no AoA effects for componential representations (e.g., reading). The same idea can also be gleaned by comparing the simulations reported in other studies (Ellis & Lambon Ralph, 2000; Monaghan & Ellis, 2002b). The principal aim of this study was to test the variation of AoA effects in a set of simple connectionist simulations and a related empirical study with human subjects. In order to draw out this contrast specifically, the simulations/experiments were designed to make the AoA manipulation, and other factors, identical across mappings/tasks. A simple three-layer feedforward model (the same as that used by Ellis & Lambon Ralph, 2000) was trained on four sets of patterns for which the same AoA manipulation was applied (a 750 epoch lag between entry of early and late patterns). As predicted, the size of the resultant AoA effect decreased across the four types of mapping. The greatest difference emerged for the arbitrary mapping, intermediate for quasisystematic and then systematic mappings, and only a very small AoA effect was found for the quasiconsistent (componential) representations. This pattern was replicated in the empirical study: A substantial AoA difference in response times was found in the picture naming task (which involves an arbitrary mapping between semantics and phonology) but no difference was found in the word naming experiment (which involves a quasi-consistent mapping between orthography and phonology) even though the same set of picturable nouns were used in both tasks.

The finding of an AoA effect in picture naming replicates many other previous studies that have consistently found a difference in this task (Barry et al., 1997; Ellis & Lambon Ralph, 2000; Monaghan & Ellis, 2002b; Morrison et al., 1992). This is true, not only for naming times in normal subjects, but also in accuracy for aphasic patients with progressive or acute brain injury (Cuetos et al., 2002; Ellis et al., 1996; Hirsh & Ellis, 1994; Lambon Ralph et al., 1998; Nickels & Howard, 1995) As noted in the introduction, the results from word naming are less clear and have provoked a recent debate (Ellis & Monaghan, 2002; Monaghan & Ellis, 2002b; Strain et al., 2002). Perhaps the most important conclusion from this literature for the present study is that, even when an AoA effect is found in reading, the size of the effect is considerably smaller than that found in picture naming—mirroring the results from the simulations reported here and elsewhere (Zevin & Seidenberg, 2002). Resolution of the exact status of AoA effects in word naming will require further empirical and computational studies. In the small simulation used here, only a very small AoA effect was found in overall reading. In their much larger and more representative simulation of monosyllabic word reading, Zevin and Seidenberg (2002) found no AoA effect. This included an investigation of reading overall in addition to words with strange body-rimes (e.g., PHLEGM). The reading simulations reported by Monaghan and Ellis (an extension to the reading simulation reported here; 2002), only found a small AoA effect for low frequency, inconsistent words.

In addition to an interaction with mapping type, the simulations and empirical studies also found an interaction between AoA and frequency. Perhaps surprisingly, this has only been investigated before in a handful of studies. The interaction revealed in this study was very similar to that reported by Gerhand and Barry (1999). Frequency effects are significantly larger for late acquired items. We found that this interaction emerged even under standard, unspeeded picture naming, while Gerhand and Barry only found an interaction when a speeded paradigm was adopted in their word naming experiment. As noted by Ellis and Lambon Ralph (2000), combined effects of AoA and frequency are both general characteristics of learning and the exact form of any interaction between the two factors depends on the degree of AoA and frequency manipulations.

This and previous studies (Ellis & Lambon Ralph, 2000; Zevin & Seidenberg, 2002) highlight the importance of three key factors: AoA, frequency, and mapping type. The impact of the mapping between representations has been noted before, not only in computational modelling studies (Plaut et al., 1996; Plaut & Shallice, 1993; Seidenberg & McClelland, 1989) but also in the neuropsychological literature. A number of authors have appealed to variation in the nature of the mapping to explain apparent dissociations in comprehension for different modalities (e.g., word vs. picture comprehension: Lambon Ralph & Howard, 2000; Plaut, 2002). In an extension to Zevin and Seidenberg's study, a fuller range of mapping types was investigated in this study. The results seem to provide an explanation for why AoA effects can be found in some but not all tasks: AoA effects are revealed for picture naming (and any other task that involves an arbitrary mappings), object categorization (which includes a quasiconsistent mapping: Lambon Ralph & Howard, 2000; Plaut, 2002) but are minimal for word naming (a domain with quasiconsistent mappings). In conclusion, the AoA literature provides another example of how basic computational principles such as frequency, plasticity, and mapping type provide important constructs for understanding cognition.

REFERENCES

Barry, C, Morrison, C. M., & Ellis, A. W. (1997). Naming the Snodgrass and Vanderwart pictures: Effects of age of acquisition, frequency and name agreement. *Quarterly Journal of Experimental Psychology*, *50A*, 560–585.

Brown, G. D. A., & Watson, F. L. (1987). First in, last out: Word learning age and spoken word frequency as predictors of word familiarity and word naming latency. *Memory and Cognition*, *15*, 208–216.

Brysbaert, M., van Wijnendaele, I., & de Deyne, S. (2000). Age-of-acquisition effects in semantic processing tasks. *Ada Psychologica*, *104*, 215–226.

Carroll, J. B., & White, M. N. (1973). Word frequency and age-of-acquisition as determiners of picture-naming latency. *Quarterly Journal of Experimental Psychology*, *25*, 85–95.

Cuetos, F., Aguado, G., Izura, C, & Ellis, A. W. (2002). Aphasic naming in Spanish: Predictors and errors. *Brain and Language*, *82*, 344–365.

Ellis, A. W., & Lambon Ralph, M. A. (2000). Connectionist networks can provide a natural account of age of acquisition effects in adult lexical processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*, 1103–1123.

Ellis, A. W., Lum, C, & Lambon Ralph, M. A. (1996). On the use of regression techniques for the analysis of single-case aphasic data. *Journal of Neurolinguistics*, *9*, 165–174.

Ellis, A. W., & Monaghan, J. (2002). Reply to Strain, Patterson and Seidenberg (2002). *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*, 215–220.

Ellis, A. W., & Morrison, C. M. (1998). Real age of acquisition effects in lexical retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *24*, 515–523.

Freud, S. (1935). *On aphasia* (E. Stengel, Trans.). London: Imago. (Original work published 1891)

Gerhand, S., & Barry, C. (1998). Word frequency effects in oral reading are not merely age-of-acquisition effects in disguise. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *24*, 267–283.

Gerhand, S., & Barry, C. (1999). Age of acquisition and frequency effects in speeded word naming. *Cognition*, *73*, B27–B36.

Gilhooly, K. J., & Watson, F. L. (1981). Word age-of-acquisition effects: A review. *Current Psychological Research*, *1*, 269–286.

Hirsh, K. W., & Ellis, A. W. (1994). Age of acquisition and lexical processing in aphasia: A case study. *Cognitive Neuropsychology*, *11*, 435–458.

Lambon Ralph, M. A., Graham, K. S., Ellis, A. W., & Hodges, J. R. (1998). Naming in semantic dementia—what matters? *Neuropsychologia*, *36*, 775–784.

Lambon Ralph, M. A., & Howard, D. (2000). Gogi aphasia or semantic dementia? Simulating and assessing poor verbal comprehension in a case of progressive fluent aphasia. *Cognitive Neuropsychology*, *17*, 437–66.

Lewis, M. B. (1999). Age of acquisition in face categorisation: Is there an instance-based account? *Cognition*, *71*, B23–B39.

McClelland, J. L., McNaughton, B. L., & O'Reilly, R. C. (1995). Why there are complementary learning-systems in the hippocampus and neocortex: Insights from the successes and failures of connectionist models of learning and memory. *Psychological Review*, *102*, 419–457.

McCloskey, M., & Cohen, N. J. (1989). Catastrophic interference in connectionist networks: The sequential learning problem. In G. H. Bower (Ed.), *The psychology of learning and motivation* (pp. 109–165). New York: Academic Press.

Monaghan, J., & Ellis, A. W. (2002a). Age of acquisition and the completeness of phonological representations. *Reading and Writing*, *15*, 759–788.

Monaghan, J., & Ellis, A. W. (2002b). What exactly interacts with spelling–sound consistency in word naming? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*, 183–206.

Monsell, S. (1991). The nature and locus of word frequency effects in reading. In D. Besner & G. W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 148–197). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Moore, V., & Valentine, T. (1998). The effect of age of acquisition on speed and accuracy of naming famous faces. *Quarterly Journal of Experimental Psychology*, *51A*, 485–513.

Moore, V., & Valentine, T. (1999). The effects of age of acquisition in processing famous faces and names: Exploring the locus and proposing a mechanism. In *Proceedings of the twenty-first annual meeting of the Cognitive Science Society, Vancouver* (pp. 148–197). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Morrison, C. M. (1993). *Loci and roles of word age of acquisition and word frequency in lexical processing*. Unpublished doctoral dissertation, University of York, UK.

Morrison, C. M., Chappell, T. D., & Ellis, A. W. (1997). Age of acquisition norms for a large set of object names and their relation to adult estimates and other variables. *Quarterly Journal of Experimental Psychology*, *50A*, 528–559.

Morrison, C. M., & Ellis, A. W. (1995). Roles of word frequency and age of acquisition in word naming and lexical decision. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 116–133.

Morrison, C. M., Ellis, A. W., & Quinlan, P. T. (1992). Age of acquisition, not word frequency, affects object naming, not object recognition. *Memory and Cognition*, *20*, 705–714.

Morton, J. (1969). The interaction of information in word recognition. *Psychological Review*, *76*, 340–354.

Munro, P. W. (1986). State-dependent factors influencing neural plasticity: A partial account of the critical period. In J. L. McClelland & D. E. Rumelhart (Eds.), *Parallel distributed processing: Explorations in the microstructure of cognition: Vol 2. Psychological and biological models*. Cambridge, MA: MIT Press.

Nickels, L., & Howard, D. (1995). Aphasic naming: What matters? *Neuropsychologia*, *33*, 1281–1303.

Plaut, D. C. (2002). Graded modality-specific specialization in semantics: A computational account of optic aphasia. *Cognitive Neuropsychology*, *19*, 603–639.

Plaut, D. C, McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review*, *103*, 56–115.

Plaut, D. C., & Shallice, T. (1993). Deep dyslexia: A case study of connectionist neuropsychology. *Cognitive Neuropsychology*, *10*, 377–500.

Seidenberg, M., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review*, *96*, 523–568.

Snodgrass, J. G., & Vanderwart, M. (1980). A standardised set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory*, *6*, 174–215.

Strain, E., Patterson, K., & Seidenberg, M. S. (2002). Theories of word naming interact with spelling–sound consistency. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*, 207–214.

Terrace, H. S. (1963). Discrimination learning with and without “errors”. *Journal of the Experimental Analysis of Behavior*, *6*, 1–27.

Turner, J. E., Valentine, T., & Ellis, A. W. (1998). Age of acquisition, not word frequency, affects auditory lexical decision. *Memory and Cognition*, *26*, 1281–1291.

Vitkovitch, M., & Tyrrell, L. (1995). Sources of disagreement in object naming. *Quarterly Journal of Experimental Psychology*, *48A*, 822–848.

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

Zevin, J. D., Seidenberg, M. S., & Bottjer, S. W. (2004). Limits on reacquisition of song in adult zebra finches exposed to white noise. *Journal of Neuroscience*, *24*, 5849–5862.

APPENDIX: Psycholinguistic details on the picturable nouns used in the empirical study

	Objective AoA	*Celex frequency*	*Visual complexity*	*Name agreement*	*Phoneme length*	*Syllable length*	*Letter length*	*Concept familiarity*	*Rated imageability*	*Rated AoA*	*Rated frequency*
Early, LF											
1 slide	22.1	9	3.95	1.00	4	1	5	2.90	5.90	2.05	2.45
2 balloon	22.1	3	1.25	1.00	5	2	7	2.86	6.55	1.80	2.90
3 banana	23.4	4	1.25	0.91	6	3	6	3.71	6.55	1.70	3.70
4 mouse	23.4	8	3.00	0.82	3	1	5	2.59	6.65	1.95	2.30
5 flag	38.5	9	2.00	1.00	4	1	4	2.22	6.35	2.80	2.15
6 lion	23.4	8	3.25	1.00	4	2	4	1.91	6.55	2.10	2.00
7 scissors	23.4	4	2.20	1.00	5	2	8	3.91	6.20	2.50	3.45
8 boot	23.4	8	2.05	0.96	3	1	4	4.23	6.05	1.90	4.15
9 candle	38.5	8	2.25	1.00	5	2	6	3.32	6.10	3.25	3.05
10 snowman	23.4	0	2.45	1.00	6	2	7	2.20	6.55	1.70	2.20
11 sock	23.4	3	1.80	1.00	3	1	4	4.73	6.20	1.65	4.05
12 carrot	25.1	3	2.65	1.00	5	2	6	4.23	6.50	2.25	3.40
13 spider	25.1	4	3.15	0.95	5	2	6	3.09	6.45	1.75	3.05
14 comb	38.5	4	2.00	1.00	3	1	4	3.68	6.15	2.55	3.05
15 pram	38.5	5	3.55	1.00	4	1	4	2.40	5.80	2.15	2.10
16 jigsaw	38.5	2	2.35	0.90	5	2	6	3.00	6.25	2.10	1.95
17 giraffe	38.5	1	4.35	0.96	5	2	7	1.55	6.40	2.65	1.85
18 duck	22.1	4	3.05	0.82	3	1	4	2.59	6.55	1.70	3.50
19 bike	23.4	8	3.85	0.64	3	1	4	4.09	6.60	2.00	3.65
20 frog	23.4	4	3.60	0.91	4	1	4	2.38	6.35	2.10	2.25
Mean	27.91	4.95	2.70	0.94	4.25	1.55	5.25	3.08	6.34	2.13	2.86
SD	7.16	2.76	0.89	0.09	1.02	0.60	1.33	0.88	0.24	0.43	0.74
Min	22.10	0	1.25	0.64	3	1	4	1.55	5.80	1.65	1.85
Max	38.50	9	4.35	1.00	6	3	8	4.73	6.65	3.25	4.15

Appendix (*Continued*)

	Objective AoA	*Celex frequency*	*Visual complexity*	*Name agreement*	*Phoneme length*	*Syllable length*	*Letter length*	*Concept familiarity*	*Rated imageability*	*Rated AoA*	*Rated frequency*
Late, LF											
1 vase	62.5	4	3.40	1.00	3	1	4	2.50	6.55	3.45	2.50
2 swan	62.5	5	2.65	1.00	4	1	4	2.23	6.55	2.90	2.45
3 ant	62.5	4	3.70	0.86	3	1	3	2.75	5.90	2.30	2.50
4 deer	86.5	6	3.35	0.77	2	1	4	1.73	6.25	2.55	1.90
5 arrow	62.5	8	1.60	1.00	3	2	5	3.27	6.30	2.85	2.20
6 ski	102.5	5	3.05	1.00	3	1	3	2.05	5.65	3.35	2.25
7 dustbin	68.5	2	2.58	0.55	7	2	7	3.50	5.75	2.50	3.40
8 torch	56.5	9	2.65	1.00	3	1	5	3.45	5.90	2.90	2.65
9 whale	56.5	6	2.85	1.00	3	1	5	3.15	6.35	2.95	2.20
10 axe	62.5	0	1.85	1.00	3	1	3	2.14	6.20	2.85	1.85
11 jug	56.5	8	1.85	1.00	3	1	3	3.23	6.30	2.60	2.40
12 fridge	56.5	4	2.40	0.70	4	1	6	4.48	6.20	2.95	4.25
13 wizard	56.5	2	4.00	0.95	5	2	6	1.50	6.15	2.75	1.90
14 plug	68.5	6	2.50	1.00	4	1	4	3.59	5.70	2.85	3.20
15 cooker	56.5	4	3.75	0.65	4	2	6	4.45	5.85	2.35	4.00
16 pumpkin	74.5	2	2.60	1.00	7	2	7	1.77	6.25	3.15	1.75
17 genie	62.5	1	3.05	1.00	4	2	5	1.65	6.35	3.80	1.45
18 yo-yo	74.5	0	2.95	1.00	4	2	4	2.15	6.20	2.60	1.60
19 grapes	56.5	8	3.35	1.00	5	1	6	3.00	6.25	2.70	3.05
20 dice	56.5	2	2.65	0.85	3	1	4	3.00	6.65	3.00	1.95
Mean	65.10	4.30	2.84	0.92	3.85	1.35	4.70	2.78	6.17	2.87	2.47
SD	11.90	2.74	0.64	0.14	1.31	0.49	1.30	0.88	0.29	0.37	0.76
Min	56.50	0	1.60	0.55	2	1	3	1.50	5.65	2.30	1.45
Max	102.50	9	4.00	1.00	7	2	7	4.48	6.65	3.80	4.25

Appendix (*Continued*)

	Objective AoA	*Celex frequency*	*Visual complexity*	*Name agreement*	*Phoneme length*	*Syllable length*	*Letter length*	*Concept familiarity*	*Rated imageability*	*Rated AoA*	*Rated frequency*
Early, HF											
1 bed	22.4	244	2.45	1.00	3	1	3	4.86	6.55	.25	4.70
2 sun	23.4	150	1.50	1.00	3	1	3	4.45	6.70	.45	3.95
3 ball	23.4	93	2.25	0.91	3	1	4	3.36	6.40	.25	3.45
4 fish	22.1	80	2.95	1.00	3	1	4	3.09	6.75	.90	3.05
5 bread	38.5	74	1.50	0.96	4	1	5	4.68	6.30	.95	4.40
6 bus	23.4	64	4.15	0.82	3	1	3	3.95	6.55	.75	3.85
7 finger	23.4	48	2.35	1.00	5	2	6	4.68	6.05	.50	3.35
8 bath	23.4	44	3.10	0.95	3	1	4	4.65	6.10	.50	4.10
9 watch	38.5	37	2.95	1.00	4	1	5	4.27	6.30	2.25	4.10
10 glasses	23.4	32	2.60	0.86	6	2	7	3.82	6.25	2.40	3.85
11 knife	23.4	35	1.95	0.96	3	1	5	4.82	6.45	2.15	4.30
12 trousers	25.1	28	2.30	1.00	6	2	8	4.90	6.20	1.95	3.90
13 wheel	25.1	28	3.35	0.86	3	1	5	2.68	6.45	2.10	2.95
14 bowl	38.5	26	1.65	1.00	3	1	4	4.09	5.85	1.50	4.05
15 castle	38.5	24	3.45	0.95	4	2	6	3.45	6.50	2.50	2.20
16 thumb	38.5	22	2.40	0.95	3	1	5	4.64	6.10	2.00	3.10
17 basket	38.5	18	3.85	0.96	6	2	6	2.27	6.20	2.65	3.00
18 cake	23.4	21	2.80	1.00	3	1	4	3.32	6.40	1.80	3.40
19 cow	23.4	22	3.85	1.00	2	1	3	3.18	6.55	1.45	2.90
20 pig	23.4	18	2.70	0.96	3	1	3	2.36	6.75	1.65	2.50
Mean	27.97	55.40	2.71	0.96	3.65	1.25	4.65	3.88	6.37	1.85	3.56
SD	7.110	55.25	0.77	0.05	1.18	0.44	1.42	0.86	0.24	0.41	0.67
Min	22.10	18	1.50	0.82	2	1	3	2.27	5.85	1.25	2.20
Max	38.50	244	4.15	1.00	6	2	8	4.90	6.75	2.65	4.70

Appendix (*Continued*)

	Objective AoA	*Celex frequency*	*Visual complexity*	*Name agreement*	*Phoneme length*	*Syllable length*	*Letter length*	*Concept familiarity*	*Rated imageability*	*Rated AoA*	*Rated frequency*
Late, HF											
1 boy	56.5	207	3.85	0.95	2	1	3	4.50	6.25	1.40	4.10
2 hair	56.5	191	2.88	0.95	2	1	4	4.45	5.75	1.50	4.25
3 king	56.5	89	3.70	1.00	3	1	4	3.00	6.35	2.05	2.05
4 desk	86.5	82	3.30	0.91	4	1	4	4.60	6.15	2.80	3.60
5 nose	56.5	73	1.35	1.00	3	1	4	4.63	5.80	1.40	3.60
6 judge	102.5	57	4.15	1.00	3	1	5	2.05	5.60	3.95	2.20
7 coat	68.5	50	2.45	1.00	3	1	4	3.77	5.75	1.90	4.00
8 shirt	56.5	45	2.95	1.00	3	1	5	4.09	6.30	2.45	3.75
9 ship	56.5	44	3.35	0.55	3	1	4	3.35	6.25	2.15	2.55
10 jacket	56.5	34	3.85	0.85	5	2	6	4.12	5.95	2.60	3.60
11 chain	56.5	33	2.50	0.96	3	1	5	2.57	5.85	2.95	2.60
12 cloud	56.5	30	1.15	1.00	4	1	5	4.05	6.60	1.90	3.35
13 shell	56.5	28	3.90	1.00	3	1	5	2.75	5.80	2.15	2.15
14 cap	68.5	27	2.18	0.91	3	1	3	2.91	5.90	2.45	2.05
15 crown	56.5	23	3.75	1.00	4	1	5	1.68	6.40	2.40	1.80
16 pipe	74.5	22	1.95	1.00	3	1	4	2.20	5.65	3.35	2.05
17 fence	62.5	22	3.10	0.91	4	1	5	2.68	5.95	2.25	2.40
18 lamp	74.5	21	1.90	0.90	4	1	4	3.73	6.00	2.85	3.55
19 skirt	56.5	20	3.15	0.90	4	1	5	3.55	6.05	2.00	3.30
20 tie	56.5	19	2.65	1.00	2	1	3	2.91	6.10	2.45	2.90
Mean	63.60	55.85	2.90	0.94	3.25	1.05	4.35	3.38	6.02	2.35	2.99
SD	12.52	53.30	0.87	0.10	0.79	0.22	0.81	0.90	0.27	0.64	0.80
Min	56.50	19	1.15	0.55	2	1	3	1.68	5.60	1.40	1.80
Max	102.50	207	4.15	1.00	5	2	6	4.63	6.60	3.95	4.25