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ARTICLE

Snapshots of Children's Changing Biases During Language Development: Differential Weighting of Perceptual and Linguistic Factors Predicts Noun Age of Acquisition

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Word learning is a lifelong activity constrained by cognitive biases that people possess at particular points in development. Age of acquisition (AoA) is a psycholinguistic variable that may prove useful toward gauging the relative weighting of different phonological, semantic, and morphological factors at different phases of language acquisition and development. Our aim here was to evaluate AoA as a statistical tool for taking ''snapshots'' of cognitive development. We examined a large corpus of English nouns ($n = 1{,}381$) with AoA as the outcome variable in three separate multivariate regressions, encompassing different age ranges (early–middle–late). Predictors included perceptual (e.g., imagery), phonological (e.g., phonological neighborhood density), and lexical (e.g., word length) factors. Different combinations of predictors accounted for significant proportions of the variance for different AoA ranges (i.e., early–middle–late). For example, imageability and frequency are stronger predictors of early relative to late word learning. These corpus analyses support a hybrid model of word learning in which multiple perceptual and linguistic factors are differentially weighted over time. This statistical approach may provide independent corroboration of and motivation for experimental studies in language learning and cognitive development.

It is no easy task to learn a word. Were it not for the seeming ease with which children will come to master word learning and employ an impressive vocabulary within a few short years of life (Brown, 1973), acquiring language would seem a daunting prospect for a small child. Children must first parse the continuous speech stream into the appropriate units (Jusczyk & Aslin, 1995), overcome the indeterminancy of a word's referent (Quine, 1960), retain a word-to-concept

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mapping over time (Paivio, 1985), and remain flexible given the ad-hoc demands of situations yet to be encountered to use that word (Barsalou, 1983). A child must then use that word productively with others—in spite of a lack of feedback as to incorrect usage (Marcus, 1993). Yet, given the benefit of using words to communicate and infer one's private intentions (Meltzoff, 1995) and shared cultural values and personal memories (Fivush & Nelson, 2004), there is no shortage of initial motivation for the child. Indeed, although children will crack the code of word learning relatively early, it is important to stress that this activity is a lifelong pursuit, immersed as it is in the changing internal, neurobiological (Friederici, 2005; Kuhl & Rivera-Gaxiola, 2008; Thompson-Schill, Ramscar, & Chrysikou, 2009), as well as cultural, cross-linguistic, and socioeconomic contexts children will face as they age into adolescence, adulthood, and older adulthood (Craik & Bialystok, 2006; Kuhl, 2007; Raizada, Richards, Meltzoff, & Kuhl, 2008; Tomasello, 2000).

How do children learn words? Not surprisingly, word learning does not occur overnight. By all accounts, this is an ability that must develop. There have been numerous theories of word learning and language acquisition, with some paradigms privileging more nativist or constraint-based accounts (Markman & Wachtel, 1988; Newport, 1990; Pinker, 1994), some more associative, learning, or statistical (Marcus, 2000; Ramscar & Gitcho, 2007; Smith, 2000), and some more social–pragmatic (Baldwin et al., 1996; Brooks & Meltzoff, 2008; Tomasello, 2005). Recently, it has been argued that given the necessity of perceptual, statistical, linguistic, and social–pragmatic abilities for word learning, only a hybrid account would seem to be capable of realistically capturing its complexity (Golinkoff & Hirsh-Pasek, 2006; see also Bloom, 2000; Hollich, Hirsh-Pasek, & Golinkoff, 2000).

Specifically, according to hybrid accounts of language acquisition, word learning is an emergent phenomenon in which the perceptual saliency of objects and the social–pragmatic factors of communication are in a sense differentially weighted at different points in a child's development. Thus, certain factors are more important to the child at different times—or otherwise are more accessible to them given their current cognitive or neurological development. In particular, given the developmental literature, a hybridized account would predict a transitional weaning from an early reliance on more general, statistical learning mechanisms (see Aslin, Saffran, & Newport, 1998) to a later focus on social–pragmatic cues during language use. Importantly, under a hybrid account, children may pay attention and cope with the word-learning task differently as they come to approximate more the symbolic and social world of adults. For example, a recent account of word learning that exemplifies this approach is Hollich et al.'s (2000) emergentist coalition model, which focuses on the transition from an associative-biased, perceptually biased child into a social-cue sophisticate. Empirical research has provided support for the model as 10-month-olds weight perceptual saliency more heavily than they weight social cues when learning words (Pruden, Hirsh-Pasek, Golinkoff, & Hennon, 2006), whereas some 12-month-olds and even more 18-month-olds pay increasing attention to social intent and gaze during word learning, though perceptual factors can still be relevant (see Hollich et al.; for an extension to verbs, see also Brandone, Pence, Golinkoff, & Hirsh-Pasek, 2007).

Numerous studies in language development have examined the influence of various linguistic variables on word learning, including the contributions of phonological, morphological–lexical, and semantic factors. Here, we would like to highlight some of them to stress how a combination of these factors, sensitive to the time in development at which they are most relevant, can contribute to language learning. Phonological variables, for example, such as the phonological complexity of a word (i.e., its length and degree of consonant clustering, as well as its etymology and primary stress) have been shown to influence language learning. For example, children's lexicons appear to include words that are high in phonological density early in development (e.g., Coady & Aslin, 2003). Furthermore, phonological density predicts word-finding success and phonological errors in young children, with increased error rates for words from sparse phonological neighborhoods (German & Newman, 2004; see also Storkel, Armbrüster, & Hogan, 2006). The length of a word has also been shown to influence language development, such that lower-syllable words are associated with faster learning and fewer errors relative to higher-syllable words among young children (e.g., Dobrich & Scarborough, 1992; Montgomery, 1995; Treiman & Zukowski, 1996). Similarly, children's ability to produce consonant clusters develops as a function of the clusters' phonological complexity (McLeod, van Doorn, & Reed, 2001a, 2001b; see also Gilbert & Purves, 1977; Treiman, Zukowski, & Richmond-Welty, 1995). Moreover, infants are sensitive to the position of a word's primary stress, which they use as a cue for word segmentation (Kemler Nelson, Hirsh-Pasek, Jusczyk, & Cassidy, 1989; Thiessen & Saffran, 2007), and they appear to be better at retaining stressed syllables while omitting unstressed syllables (Carter & Gerken, 2004; Jarmulowicz, 2002). Finally, information on word origin may support language learning, such that knowledge of a word's etymology can guide letter–sound correspondence and spelling achievement among older children (see Henry, 1989). Although this survey of research on phonological variables does not focus on the ways in which such variables are related to different aspects of a child's language learning (i.e., comprehension vs. production), it nonetheless underscores their importance as a factor in any developmental account of language.

With regards to morphological–lexical factors, the degree of complexity of a word's structure significantly influences language learning, such that morphologically complex words are harder to remember than morphologically simple words (e.g., Service & Tujulin, 2002). Furthermore, children's word formation appears to be sensitive to the presence of compounding during early language development (e.g., Alegre & Gordon, 1996; Gordon, 1985). Critically, the development of children's phonological processing is significantly determined by the frequency of a word: High-frequency items are named faster and more accurately than are low-frequency items, and high-frequency items dominate the lexicons of young toddlers (see Rescorla, Alley, & Christine, 2001; Troia, Roth, & Yeni-Komshian, 1996).

Regarding the influence of semantic factors, several studies have demonstrated that children are sensitive to the effects of word familiarity from a very young age. For example, familiar word forms are recognized faster and are associated with lower error rates relative to unfamiliar word forms (e.g., Anderson, 2007; Taylor & Gelman, 1989; Vihman, Thierry, Lum, Keren-Portnoy, & Martin, 2007). Word imageability (i.e., the extent to which a word can produce a mental image) has also been shown to influence reading accuracy and short-term memory, such that high-imageable words are read faster and remembered better compared with low-imageable words (e.g., Coltheart, Laxon, & Keating, 1988; Majerus & Van der Linden, 2003).

Even though earlier work has identified the importance of each of these phonological, morphological, and semantic factors for the development of word learning, no study to our knowledge has explored statistically the relative contribution of each of these characteristics in determining the age a given word is acquired (i.e., age of acquisition [AoA]). Under a dynamic hybrid account of language learning, one could predict that children will be attuned to different phonological, morphological, and semantic word features at different times in their lives, depending on their current cognitive or neurological development. Consequently, we aimed to investigate statistically the manner in which different combinations of these factors are weighted as more or less important for language learning depending on the development of the child.

Development can be operationalized as the differential ability of participants of various ages to perform tasks. (We acknowledge, of course, that there are different ways to operationalize development and will advance an alternative ourselves.) Development would thus be shown with a change in performance over time. Age, in the sense we are now discussing it, could then be used as an organismic variable to divide subjects into separate groups of interest. For example, language development could be studied cross-sectionally (younger vs. young) or longitudinally (Time 1 vs. Time 2) with respect to children's abilities to perform sound discrimination or novel word-learning tasks, given certain natural or constructed stimuli (e.g., contrasting phoneme sets or nonsense words). Fundamentally, different ages predict different behavior, or the study's ''dependent'' variable (see Aslin & Fiser, 2005, for a welcome criticism). In this vein, previous research with adult populations has treated the AoA of words (the age at which a word is learned) as a predictor variable (akin to word frequency, word length, or concreteness) for linguistic performance in healthy and neuropsychological patient populations (see Juhasz, 2005, for a review).

A word's AoA is a discrete psycholinguistic variable that refers to chronological variability in lexical acquisition. The largest corpora of AoA values have been derived through adults' retrospective estimation of when they acquired a word or concept (Bird, Franklin, & Howard, 2001; Gilhooly & Logie, 1980). These adult subjective AoA ratings, which rely upon remote source memory, importantly, correlate strongly with more objective methods of obtaining AoA. For example, concordance between AoA and lexical acquisition has been established through a variety of experimental and naturalistic means, including diary studies of production, preferential looking-time comprehension tasks, and standardized school-based vocabulary assessments (for review of specific assessments, see Morrison, Chappell, & Ellis, 1997). Critically, Morrison et al. (1997) reported a small set of objective AoA norms ($N = 297$ words) derived from picture naming. The correlation between these objective norms and the Gilhooly and Logie adult subjective ratings was $r = .75$. A second source of converging evidence for the validity of subjective AoA norms comes from a longitudinal study of vocabulary acquisition, comparing childhood subjective ratings at ages 9 and 11 with adult subjective AoA norms. Adults' subjective ratings correlated strongly with children's ($r = .82$). In addition, children's subjective ratings correlated with actual acquisition as measured by observational records of when words were first spoken or read ($r = .71$ for speech, and $r = .77$ for text; see Zevin & Seidenberg, 2002). Accordingly, subjective AoA norms are a valid and robust measure of lexical acquisition.

AoA norms have been used in numerous contexts in psycholinguistic research to inform accounts of performance patterns in a variety of language tasks. For example, a common finding is that words with earlier AoA are processed more rapidly and are more resilient to neurological disease (e.g., aphasia, dementia) than those with later AoA (see Cuetos, Rosci, Laiacona, & Capitani, 2008; Ellis & Lambon Ralph, 2000), and AoA can be used to predict dependent measures like lexical decision latency and speeded-naming responses (e.g., Catling & Johnston, 2009). In studies with both adults and children, this ''age'' variable is treated like any other psycholinguistic variable (e.g., word frequency)—to be manipulated and controlled. It is somewhat paradoxical, however, to consider the age at which a word is learned to be a ''property'' of a word like the seemingly more inherent psycholinguistic variable of a word's length or its number of morphemes. That is, a word is always only so many letters, and this length is irrespective of the age of the individual who hears it. The age of a child, however—specifically with respect to when he or she is able to accomplish a particular task like learning a word—could be treated in a very different manner: Rather than as a predictor of behavior or the presence of some linguistic milestone, the AoA of words can be treated as an outcome variable.

Reilly, Chrysikou, and Ramey (2007), in fact, recently evaluated the relative importance of various psycholinguistic factors that contribute to English noun acquisition by treating AoA as an outcome variable in a multivariate regression analysis. Specifically, factors such as imageability and number of morphemes were acquired from linguistic corpora and used to predict the age at which a word was learned. Thus, the psycholinguistic profile of a word predicted the age of the individual who had learned it, rather than age predicting some ability or its absence, as is commonly the case at least in the adult psycholinguistics literature. Ma, Golinkoff, Hirsh-Pasek, McDonough, and Tardiff (2009) have already recently demonstrated that imageability was a significant predictor of AoA for both nouns and verbs in Chinese. We believe that a statistical and methodological approach that treats AoA as an outcome variable in a multivariate regression could also contribute more generally to developmental theories of word learning that take into account the perceptual, statistical, and social–pragmatic factors.

Building upon the methodology introduced in Reilly et al. (2007; see also Ma et al., 2009), in this study, we reconceptualized AoA in a dramatically different manner than is common in the adult literature as we approached it as a ‘‘snapshot’’ of the learning system (in this instance, the language learner) so that multiple snapshots (i.e., early, middle, and late AoA ranges) can be taken to indicate the dynamic development of that system. Specifically, we performed a series of multivariate regression analyses to determine those phonological, morphological–lexical, and syntactic factors—shown to influence language development in general in earlier studies—that predict the AoA of English nouns at different developmental points. Along the lines discussed above, if a child differentially weights certain factors for word learning earlier during development rather than later (e.g., decreasing reliance on perceptual or statistical factors like word frequency and consonant clustering over developmental time), then an analysis of those factors should reveal their changing weights. Thus, by contrasting words with different AoA ranges (e.g., earlier AoA vs. later AoA), it is possible to create a series of snapshots of the developing mind—or of those factors to which it is most attuned when acquiring words successfully. This is on par with a memory researcher using differential performance on a recall task under a certain interference condition (relative to not) as inferential evidence for the mechanism being interfered with.

In the regression analyses to follow, we entered a variety of phonological, morphological, and semantic factors as predictors of AoA at different time points during early childhood development. Our aim was to capture the weighted contribution of salient psycholinguistic variables from the following categories: phonology, syntax, lexical representation, and semantics. Although there are clearly additional constraints on word learning (e.g., social intent), statistical analyses were limited to previously quantified characteristics of words. That is, there exist no measurable item-level norms for statistical assessment of social intent (e.g., a Likert-like value for a child’s motivation to learn the word *computer*). However, there do exist validated, quantifiable norms within the categories of phonology, morphology, and semantics. The inclusion of specific predictors in our regression models was based on earlier research demonstrating the effects of each of these classes of variables on language acquisition and processing as previously discussed. A brief discussion of these variables follows.

Phonological Predictors

Much is known about the contribution of phonological complexity to language processing. Although an exhaustive list of phonological and acoustic–phonetic variables is beyond the scope of a single analysis, there are several overarching constructs that have proven to be of particular importance for word learning. One consistent difficulty in parsing the unique variance of these constructs is that many are strongly correlated. For example, as words lengthen, they tend to have fewer similar-sounding neighbors and are composed of lower probability phonotactic combinations (Storkel et al., 2006). Such correlations between word length and phonological complexity present collinearity problems for many statistical procedures. Therefore, we selected constructs for which the correlations were insufficient to compromise collinearity but whose importance has been emphasized across numerous studies of lexical acquisition. These included: 1) *phonological neighborhood density* (i.e., density of similar-sounding words to a target word; e.g., Coady & Aslin, 2003); 2) *word length* (e.g., Treiman & Zukowski, 1996); 3) *consonant clustering* (e.g., McLeod et al., 2001a, 2001b); 4) *primary segmental stress* (e.g., Kemler Nelson et al., 1989; Thiessen & Saffran, 2007); and 5) *etymology* (word origin; Henry, 1989).

Morphological and Lexical Predictors

In our regression models, we restrict our analyses to a corpus of English nouns to control for grammatical class effects. With respect to morphology, we included the following variables: 1) *total number of morphemes* (bound + unbound) per word (see Brown, 1973), and 2) *presence of compounding* (e.g., *catfish*, see Zukowski, 2005). We analyzed *word frequency* as a variable that has consistently been linked to lexical representation, lexical access, and word recognition (see Burani, Arduino, & Barca, 2007; Newman & German, 2002).

Semantic Predictors

Several quantifiable, psycholinguistic constructs capture aspects of word meaning. We selected the following semantic predictors: 1) *word imageability* (i.e., the extent to which a word can be experienced through the senses; see Paivio, 1985), and 2) *word familiarity* (i.e., the extent to which raters evaluate familiarity with a word's referent; see Zevin & Seidenberg, 2002).

Within the context of a dynamic hybrid account of language learning, we predict that different profiles of phonological, morphological, and semantic variables will be more or less important in accounting for a word's early-, middle-, and late-childhood AoA. These changing profiles would, thus, reflect the child's cognitive and neurological development at each developmental stage. Specifically, we predict that early in development, phonological and morphological factors (e.g., phonological neighborhood density, word frequency) might be of higher importance than they would be later in development, because at this age, the child's first language task is to parse the speech stream into its appropriate units (i.e., words; Jusczyk & Aslin, 1995). Were phonological factors to be unable to predict early AoA, for example, we would accordingly have little confidence in the regression model's predictive validity given the extensive developmental literature on the topic. We further predict that semantic factors will also be weighted more heavily for words acquired in early and middle childhood, as children of this age have to overcome the indeterminancy of a word's referent (Quine, 1960) and retain word-to-concept mappings over time (Paivio, 1985); that is, we would expect the profile of a word's earlier—as opposed to later—AoA to rely more heavily on concrete imageability. Finally, we expect the overall contribution of these more perceptual linguistic factors to diminish from earlier to later time points, because as children get older and begin to use words productively with others for communication, they pay more attention to social–pragmatic cues (e.g., social intent, gaze) than to perceptual cues during word learning (e.g., Brandone et al., 2007; Pruden et al., 2006).

MULTIPLE REGRESSION ANALYSES OF VARIABLES PREDICTING EARLY, MIDDLE, AND LATE AOA

Method

Construction of the Noun Corpus

The noun corpus for the present analyses was constructed from the Medical Research Council (MRC) Psycholinguistic Database (Coltheart, 1981; http://www.psych.rl.ac.uk). After the application of a series of exclusion criteria (see Reilly et al., 2007), we obtained a corpus of 2,877 nouns, which were coded on the following characteristics, according to the factors regularly employed in the literature.

Age of acquisition. AoA values for each noun were obtained from the Gilhooly and Logie (1980) adult subjective rating norms, as renormed in the MRC database. AoA values were scaled to a 100- to 700-point range using the following formula: AoA rating $= (100 \times 1$ [0–2 years], 100×2 [2–4, years], 100×3 [4–6 years], 100×4 [6–8 years], 100×5 [8–10 years], 100×6 [11–12 years], and 100×7 [13 years on]; $\mu = 405$; $\sigma = 120$, range = 125–697; for normative procedure, see Coltheart, 1981). The particular AoA norms were selected due to their applicability in a word corpus large enough to allow for the specific multivariate analyses performed in the present research. Even though these subjective norms were derived from adults' retrospective estimates of when they acquired a word or a concept (Bird et al., 2001; Gilhooly & Logie), their validity as an independent psycholinguistic variable is confirmed by their high correlation with more objective methods of obtaining AoA estimates directly from children (see Morrison et al., 1997; Morrison, Hirsh, Chappell, & Ellis, 2002; see also Funnell, Hughes, & Woodcock, 2006; Morrison & Ellis, 2000; Zevin & Seidenberg, 2002). Importantly, our previous work (Reilly et al., 2007) applying a multivariate methodology on both subjective AoA norms (Gilhooly & Logie) and a smaller corpus of objective AoA norms ($N = 297$; Morrison et al., 1997) has reliably elicited highly similar findings. Given these results, we regard the subjective corpus employed in the present analyses as highly representative of the objective AoA norms, which, due to their very small sample size and insufficient power to detect multivariate effects, could not be examined here directly (see Tabachnick & Fidell, 2001).

Word familiarity. Word familiarity values were obtained from the MRC norms (Coltheart, 1981; Gilhooly & Logie, 1980; Toglia & Battig, 1978). Familiarity values were scaled to a range of 100 to 700 ($\mu = 488$, $\sigma = 99$).

Imageability. Imageability has been defined as the extent to which a word rapidly evokes a strong mental image (e.g., *dog* is rated as highly imageable, whereas imageability ratings for *truth* are lower, indicating something abstract). The MRC database merges three of the most widely utilized imageability data sets in psycholinguistic research (i.e., Gilhooly & Logie, 1980; Paivio, Yuille, & Madigan, 1968; Toglia & Battig, 1978). Imageability ratings of these separate data sets were rescaled to form a continuous distribution with values that range from 100 (least imageable) to 700 (most imageable; $\mu = 456$, $\sigma = 108$).

Word frequency. A measure of word frequency was obtained for each item from written frequency in sources of common text (Kučera & Francis, 1982).[1]

Word length (syllables). Entries were coded for total syllables.

Consonant clustering. Individual syllables were coded categorically as phonologically *simple* or *complex*; simple structures were operationalized as free of consonant clusters. A measure of phonological complexity was derived by calculating the total number of complex syllables per word.

Morphology/derivational complexity. Derivational complexity was coded by counting total word stems, prefixes, and suffixes.

Compounding. Rate of compounding was also coded as a separate categorical independent variable. Compound words (e.g., *fireplace, bulldog*) were coded as monomorphemic rather than treating one component as a prefix/suffix (see Brown, 1973).

Etymology/word origin. Noun origin was traced to its earliest known entry in the English language (Oxford English Dictionary, 1989). All entries were then grouped into the five most commonly occurring etymologies across the dataset (i.e., Germanic, Latinate, Greek, Unknown, Other).

Phonological neighborhood density. This is composed of the set of words that differ from a target by only the substitution, addition, or omission of one phoneme (Luce & Pisoni, 1998). For example, a phonological neighborhood for the target ''cat'' would include neighbors such as ''sat,'' ''at,'' ''cot,'' and ''cap.'' Neighborhood density values were obtained from the Washington University Speech and Hearing Laboratory (http://128.252.27.56/neighborhood/Home.asp/).

Primary stress. Entries were nominally coded for primary syllable stress (e.g., *whískey* vs. *guitár*). Coding was completed for words with more than one syllable and fewer than six. For multisyllabic words, stress was determined based on the origin of the word (e.g., words with Germanic origin tend to have first syllable stress, whereas words with Latinate origin and many other language families have noninitial stress). The rules governing which syllable received the primary stress came from the language in which the word was originally derived.

[1]We recognize that there are alternative metrics of word frequency using hypertext (Lund & Burgess, 1996, as provided in the English Lexicon Project [elexicon.wustl.edu]; Balota et al., 2007) and film subtitles (Brysbaert & New, 2009) that may be superior to Kučera and Francis's (1982) text-based frequency estimates in some respects. However, use of these alternative metrics had the potential to create serious collinearity problems with the other predictor variables in this analysis. If anything, using the Kučera and Francis norms in the present analyses would have put our hypotheses at a disadvantage—something that ultimately did not appear to affect our ability to predict words' AoA.

AoA norms were available for 1,381 of the original 2,877 nouns from the MRC database; thus, only entries with corresponding AoA values were included in the present analyses. Based on earlier findings revealing significant correlations between these factors and AoA (see Reilly et al., 2007; Reilly & Kean, 2007), we hypothesized that the earlier-mentioned characteristics account for a word's AoA in various degrees. Importantly, we propose that a different combination of these variables might be of particular importance for words acquired earlier rather than later, depending on children's cognitive dispositions at various developmental stages.

Words' AoA are not evenly distributed throughout the noun corpus. Accordingly, we divided the noun corpus into three subcorpora based on the words' AoA: early AoA, with AoA ranging from 125 to 354 ($N = 461$); middle AoA, with AoA ranging from 356 to 464 ($N = 466$); and late AoA, with AoA ranging from 466 to 689 ($N = 424$). By dividing the noun corpus, we could maximize two objectives: 1) approximately equal numbers of observations among each subcorpus to allow for adequate power for multivariate regression analyses at all three AoA ranges, and 2) approximately equal AoA intervals for the early- and late-AoA ranges, in particular, to allow for substantive contrasts between these two ages. (For the latter point, regardless of the factors that predict middle-AoA words, which may indicate a developmental transition, we predict more pronounced differences in the profiles of factors involved in early-AoA and late-AoA words and so those subcorpora are of primary importance to test.) Each of the three subcorpora was then subjected to a standard multiple regression analysis, with AoA as the dependent variable and the same 10 predictors: familiarity, imageability, word frequency, syllables per word, number of consonant clusters per word, morphemes per word, compounding, word etymology, phonological neighborhood density, and stress. The ratio of cases to the number of independent variables was satisfactory for all analyses (minimum number of cases required, $N = 62$ for the detection of a medium effect, $f^2 = .15$).

Results

Early AoA

Preparation for multiple regression analysis. No significant violations of the regression assumptions were observed.[2] The assumption of linearity was not satisfied for word frequency; consequently, to improve extreme skewness and kurtosis, this variable was logarithmically transformed. No univariate outliers were identified. Following the criterion of Mahalanobis distance,

[2]Prior to analysis, variables were examined by means of various programs provided in the Statistical Package for the Social Sciences for accuracy of data entry, missing values, and fit between the distributions of each variable and the assumptions of multivariate analysis. The results of the evaluation of assumptions did not identify missing values for any of the variables. In addition, no violations of homoscedasticity and no significant violations of normality were observed. Regarding the assumptions of multicollinearity and singularity, squared multiple correlations (SMC) were calculated for each variable and converted to tolerances (1-SMC). None of the tolerances approached 0, hence satisfying the singularity and multicollinearity assumptions. Additionally, all variables entered the regression equation without violating the default value for tolerance, which further resolved doubts about possible multicollinearity and singularity among the independent variables. Finally, the highest correlations among the variables did not exceed $r = .65$, which further supports the conclusion that the multivariate assumptions were adequately satisfied (see Tabachnick & Fidell, 2001, pp. 56–110).

24 cases were found to be multivariate outliers with $p < .001$. All outliers were deleted, leaving 437 cases for analysis.

Results of multiple regression analysis. Due to lack of variability in the scores, the variables of compounding ($M = 0$, $SD = 0$) and word stress ($M = 1$, $SD = 0$) were excluded from the analysis. Table 1 displays the correlations between all remaining predictor variables and AoA, the unstandardized regression coefficients (B) and intercept, the standardized regression coefficients (β), the semipartial correlations (sr_i^2), R^2, and adjusted R^2. The regression model fits the data well, $F(8,428) = 40.99$, $p < .001$, $f^2 = .75$, mean square residual = 1,414.49. For the four regression coefficients that differed significantly from 0, 95% confidence intervals for B confirmed the significance of these factors. The independent variables that contributed significantly to AoA were familiarity ($sr_i^2 = .17$), imageability ($sr_i^2 = .11$), (log) frequency ($sr_i^2 = .01$), and number of syllables ($sr_i^2 = .01$). These four variables in combination contributed another 12% in shared variability. Altogether, 43% (42% adjusted) of the variability in AoA was predicted by knowing these characteristics of a word. Post-hoc evaluations revealed significant correlations between AoA and number of consonant clusters, $F(8,428) = 5.00$, $p < .01$, $f^2 = .02$; number of morphemes, $F(8,428) = 5.70$, $p < .01$, $f^2 = .03$; etymology, $F(8,428) = 3.57$, $p < .01$, $f^2 = .02$; and phonological neighborhood density, $F(8,428) = 12.13$, $p < .001$, $f^2 = .06$—relationships that appear to be mediated by the contributions of the primary four factors. Overall, the results of the regression analysis showed that according to our predictions, a combination of phonological, morphological, and semantic factors predicted early AoA, with some factors (e.g., word imageability) being weighted more heavily than others (e.g., number of syllables).

TABLE 1
Standard Multiple Regression Analysis of Noun Characteristics on AoA in Early Cohort ($N = 437$)

Variables	*AoA*	*FAM*	*IMAG*	*FREQ*	*NSYL*	*NCON*	*NMRPH*	*ETYM*	*DENS*	*B*	*β*	*sr²*
FAM	−.44**									−0.50**	−.54	.17
IMAG	−.40**	−.03								−.026**	−.36	.11
FREQ	−.13**	.63**	−.19**							11.07**	.13	.01
NSYL	.17**	.06	<.01	.04						11.25*	.13	.01
NCON	.15**	−.03	−.13**	.04	−.15**					7.05	.07	
NMRPH	.16**	.04	−.19**	.01	.33**	.02				8.61	.04	
ETYM	−.13**	−.06	.13**	−.08	−.17**	−.08*	−.10*			−2.40	−.05	
DENS	−.23**	−.02	.08	−.03	−.63**	−.31**	−.24**	.23**		−0.44	−.09	
										Intercept = 658.93		
Means	281.61	541.50	547.09	1.43	1.44	0.37	1.07	2.00	11.28			
Standard deviations	49.52	54.23	68.24	0.58	0.57	0.49	0.25	1.06	9.61			
										$R^2 = .43$[a]		
										Adjusted $R^2 = .42$		
										$R = .66$**		

*$p \leq .05$. **$p < .01$.

[a]Unique variability = .31; shared variability = .12.

AoA = age of acquisition; *FAM* = familiarity; *IMAG* = imageability; *FREQ* = log of text frequency; *NSYL* = number of syllables; *NCON* = number of consonant clusters; *NMRPH* = number of morphemes; *ETYM* = etymology; *DENS* = phonological neighborhood density; *B* = unstandardized regression coefficients; *β* = standardized regression coefficients; *sr²* = semipartial correlations.

Middle AoA

Preparation for multiple regression analysis. Similar to the earlier analysis, no significant violations of the regression assumptions were observed. The variable of word frequency was logarithmically transformed as violating the assumption of linearity. No univariate outliers were identified; however, following the criterion of Mahalanobis distance, 21 cases were found to be multivariate outliers with $p < .001$. All outliers were deleted, leaving 445 cases for analysis.

Results of multiple regression analysis. The variable of compounding was excluded from the model as exhibiting insufficient variability ($M = 0$, $SD = 0$). Moreover, the variable of word frequency was not correlated with the dependent variable of AoA; hence, it was excluded from the regression. Table 2 displays the correlations between all other variables and AoA and the results of the multiple regression analysis. The regression model fits the data well, $F(8,436) = 12.90$, $p < .001$, $f^2 = .23$, mean square residual = 808.69. For the four regression coefficients that differed significantly from 0, 95% confidence intervals for B confirmed the significance of the factors. The variables that contributed significantly to AoA were familiarity ($sr_i^2 = .08$), imageability ($sr_i^2 = .09$), number of syllables ($sr_i^2 = .01$), and word stress ($sr_i^2 = .01$). These variables in combination contributed another 1% in shared variability. Altogether, 19% (17% adjusted) of the variability in AoA was predicted by knowing these characteristics of a word. Post-hoc evaluations did not reveal a significant correlation between AoA and any of the remaining variables ($ps > .05$). Overall, relative to early AoA, middle AoA was predicted by a different combination

TABLE 2
Standard Multiple Regression Analysis of Noun Characteristics on AoA in the Middle Cohort ($N = 445$)

Variables	*AoA*	*FAM*	*IMAG*	*NSYL*	*NCON*	*NMRPH*	*ETYM*	*DENS*	*STRS*	*B*	*β*	*sr*²
FAM	−.11*									−0.17**	−.32	.08
IMAG	−.28**	−.44**								−0.14**	−.34	.09
NSYL	.19**	.18**	−.16**							5.53*	.15	.01
NCON	.08*	.07	−.12**	−.11**						3.82	.07	
NMRPH	.10*	.10*	−.16**	.53**	.08					−4.66	−.08	
ETYM	−.10*	−.14**	.16**	−.28**	<−.01	−.17**				−1.08	−.04	
DENS	−.18**	−.14**	.16**	−.62**	−.16**	−.32**	.21**			−0.23	−.05	
STRS	.21**	.27**	−.39**	.46**	.09*	.43**	−.14**	−.29**		7.82*	.10	.01
											Intercept = 547.96	
Means	410.34	495.16	469.16	1.96	0.48	1.26	1.68	5.39	1.18			
Standard deviations	31.34	57.96	78.50	0.86	0.56	0.51	1.10	7.42	0.40			
											$R^2 = .19^a$	
											Adjusted $R^2 = .17$	
											$R = .44^{**}$	

*$p < .05$. **$p < .01$.

[a]Unique variability = .19; shared variability = .01.

AoA = age of acquisition; *FAM* = familiarity; *IMAG* = imageability; *NSYL* = number of syllables; *NCON* = number of consonant clusters; *NMRPH* = number of morphemes; *ETYM* = etymology; *DENS* = phonological neighborhood density; *STRS* = stress; *B* = unstandardized regression coefficients; *β* = standardized regression coefficients; sr^2 = semipartial correlations.

of variables. Critically, the relative importance of factors that appeared to be central for early AoA (e.g., word familiarity, imageability) were now less important as indicated by the variables' lower weights, or were no longer correlated with AoA at all (e.g., phonological neighborhood density, word frequency). In contrast, new variables (e.g., word stress) seemed to have a stronger impact for middle AoA.

Late AoA

Preparation for multiple regression analysis. No significant violations of the assumptions for regression analysis were observed. Due to violations of linearity, the variable of word frequency was logarithmically transformed. No univariate outliers were found; however, following the criterion of Mahalanobis distance, 12 cases were identified as multivariate outliers with $p < .001$. All outliers were deleted, leaving 412 cases for analysis.

Results of multiple regression analysis. The variable of compounding was excluded as exhibiting insufficient variability ($M = 0$, $SD = 0$). In addition, the variables of consonant clustering and etymology were not correlated with the dependent variable of AoA; hence, they were excluded from the regression model. Table 3 displays the correlations between the remaining variables and AoA, as well as the results of the multiple regression analysis. The regression model fits the data well, $F(7,404) = 52.05$, $p < .001$, $f^2 = .89$, mean square residual = 1401.62. For the three regression coefficients that differed significantly from 0, 95% confidence intervals for B confirmed the significance of the factors. The variables that contributed significantly to AoA were familiarity ($sr_i^2 = .14$), imageability ($sr_i^2 = .03$).03), and number of syllables ($sr_i^2 = .02$). These

TABLE 3
Standard Multiple Regression Analysis of Noun Characteristics on AoA in the Late Cohort ($N = 412$)

Variables	*AoA*	*FAM*	*IMAG*	*FREQ*	*NSYL*	*NMRPH*	*DENS*	*STRS*	*B*	*β*	*sr²*
FAM	−.60**								−0.39**	−.56	.14
IMAG	−.28**	.08*							−0.12**	−.19	.03
FREQ	−.44**	.73**	−.04						−4.00	−.05	
NSYL	.25**	.08	−.18**	.06					11.04**	.24	.02
NMRPH	.15**	.07	−.24**	.02	.62**				−1.64	−.03	
DENS	−.16**	−.05	.12**	−.04	−.52**	−.32**			−0.94	−.04	
STRS	.12**	.12**	−.07	.05	.60**	.39**	−.27**		1.74	.03	
										Intercept = 731.51	
Means	537.46	443.72	395.82	1.05	3.02	1.81	1.13	1.62			
Standard deviations	51.19	73.77	78.21	0.64	1.11	0.82	2.31	0.81			
										$R^2 = .47^a$ Adjusted $R^2 = .47$ $R = .69^{**}$	

*$p < .05$. **$p < .01$.
[a]Unique variability = .19; shared variability = .28.
AoA = age of acquisition; *FAM* = familiarity; *IMAG* = imageability; *FREQ* = log of text frequency; *NSYL* = number of syllables; *NMRPH* = number of morphemes; *DENS* = phonological neighborhood density; *STRS* = stress; *B* = unstandardized regression coefficients; *β* = standardized regression coefficients; *sr²* = semipartial correlations.

variables in combination contributed another 28% in shared variability. Altogether, 47% (47% adjusted) of the variability in AoA was predicted by knowing these characteristics of a word. Post-hoc evaluations revealed a significant correlation between AoA and word frequency, $F(7, 404) = 13.86, p < .001, f^2 = .24$, which suggests this relationship is mediated by the correlations between AoA and familiarity, imageability, and number of syllables. In line with the prediction that phonological and morphological factors are weighted less during late language learning, post-hoc evaluations between AoA and number of morphemes, phonological neighborhood density, or primary stress were not significant.

The three multiple regression analyses reported addressed the hypothesis that a word's AoA reflects the developing child's changing biases. In particular, it was revealed that familiarity, imageability, and word length are generally important to predicting AoA, but that their importance decreases over time. In addition, phonological and especially frequency factors are important chiefly during the earliest stages of language acquisition.

GENERAL DISCUSSION

The principal appeal of any hybrid model of word learning is that it takes into account different factors—though perhaps to different degrees—without reducing the phenomenon to a single and unrealistic causal model (e.g., either perceptual or linguistic; Golinkoff & Hirsh-Pasek, 2006). Should one also consider how this differential weighting could itself change during the course of development (e.g., with regards to plasticity and maturational constraints on linguistic competency; Goldowsky & Newport, 1993; Kuhl & Rivera-Gaxiola, 2008; Shaw et al., 2006; Thompson-Schill et al., 2009), one can achieve a plausible model of word learning during a person's lifespan. That is, children may come to the task of word learning differently depending on the cognitive biases they possess at particular points in development (see Auer & Bernstein, 2008, for an example), and these early biases may no longer be present or weighted the same way later in life when presented, for example, with the task of learning a second language or recovering abilities after neurological insult in older adulthood.

In this article, we treated the age of a word's acquisition as an outcome variable in a series of multivariate regressions. Following the methodology first proposed by Reilly et al. (2007), rather than treating ''age'' as a predictor of some dependent variable, we reversed the procedure and took ''age'' (i.e., AoA of a word) as a snapshot of a person's mind at a particular developmental point characterized by certain predicting factors (e.g., certain relative biases to perceptual or linguistic features in their environment).

Results indicate that children differentially weight factors over time in accord with hybrid models (cf. Hollich et al., 2000). For example, although the imageability of a word's referent—a perceptual factor—remains a significant variable across the age ranges of our linguistic corpora, its importance decreases from early to middle to late AoA (from 11% to 9% to 3% of variance accounted for, respectively; cf. Pruden et al., 2006). Not surprisingly, children also rely more on word frequency earlier rather than later in development (i.e., frequency was a significant predictor of early AoA). Thus, a child's reliance on object and word saliency decreases with time, presumably because more adult interactions require communication of abstract, decontextualized ideas. These abstract ideas are also likely to be compact in form (Reilly, Ramey, & Milsark, 2004). For example, word length (as measured by the number of syllables) remained a significant predictor of AoA across all developmental time points as shorter words were learned before longer words. Word length (as measured by number of morphemes) predicted early AoA and late AoA, as words learned later tend to have more morphemes (see also Reilly et al., 2007).

Of particular note in our regressions is the initial importance of phonological factors in word learning. Phonemes are the smallest unit of sound that distinguishes meaning for a native speaker (see Saffran, Werker, & Werner, 2006), and their determination is an important component to the earliest stages of word learning (Eimas, Siqueland, Jusczyk, & Vigorito, 1971; see also Friederici, 2005). Although the smaller sample sizes per cohort (early, middle, and late AoA) may have decreased our power to detect the significance of this predictor, the post-hoc evaluations revealed that phonological neighborhood density was significantly correlated with AoA; importantly, this factor appeared to be influential only in the early relative to the middle and late cohorts. Thus, even though it is prima facie an easier task for children to learn words with lower phonological neighborhood density (e.g., ''dragon,'' a word with few—if any—words that differ from it by one phoneme), children initially tend to learn words characterized by a greater phonological neighborhood density (e.g., ''cat'' and ''bat''—words only differing by one phoneme). One reason for a bias toward this more competitive set of word targets could be statistical. Children may seek the most information for their efforts, namely which sounds are important enough to distinguish meaning. Determining that /c/ and /b/ are meaningful distinctions in one's language can lead to learning statistical patterns of important, recurring sounds (like words; see Saffran, Aslin, & Newport, 1996). Any initial statistical bias for phonemic contrasts, of course, would only be part of the larger and dynamic language-learning task we are proposing, as a child attending to this variable would also be developing his or her own proficiency with speech production in dyadic, meaningful social encounters with adults. One could nonetheless argue that our analyses merely predict that ''easier'' words (e.g., ''cat'') are learned earlier than ''harder'' ones (e.g., ''dragon'') and that with experience comes knowledge and a certain expertise with words. According to our proposal, however, critically the task of word learning is approached fundamentally differently depending on the age and development of the word learner. Whatever a person is at one point in his or her life, it is not merely an accumulation of exposure to words. For example, after the early-AoA cohort, our analyses indicate that the variable phonological neighborhood is no longer on the radar for children. Children have, relatively speaking, moved on. Our statistical and methodological approach allows for a new characterization of AoA, according to which we can determine the changing phonological, morphological, and semantic factors to which a child is attending and so glimpse the different developmental states of the language-learning system. It would not be unreasonable to characterize our ''snapshots'' as glimpses of the word-learning ''expert'' so long as it is recognized that the ''expertise'' is changing because the task of word learning is dynamic and itself changing. Thus, early AoA and late AoA are successive ''snapshots'' for the developing mind. Finally, regarding the correlation between word stress and AoA, even though it was excluded from the regression model for the early cohort due to lack of variability, it served as a predictor of (and was significantly correlated with) AoA for the middle cohort, though not the late AoA cohort. Thus, children's initial concern for phonological factors fades, presumably once they have determined those phonemic building blocks relevant in their native tongue.

Using AoA as an outcome variable reveals an interesting profile for those words learned early in life that may have implications for the preparedness of the adult mind to language learning (for a related account that deals with differences in processing capacities and working memory span between children and adults, see Goldowsky & Newport, 1993). Given that children, who crack the code of their native language, are attending to statistical and phonological properties early and not late (relatively speaking), an adolescent, adult, or older adult attempting to learn a second language, for example, may not be attuned to the word-learning problem in the same way. Thus, words will appear to run together and be spoken too quickly to understand because in a sense, it has been years since something like phonological neighborhood density was a relevant part of word learning for them. We believe this may also apply to any rehabilitative attempts for older adults following neurological insult (see Brysbaert, Wijnendaele, & Deyne, 2000; Cuetos, Herrera, & Ellis, 2010; Hirsh & Ellis, 1994; Holmes, Fitch, & Ellis, 2006; Nickels & Howard, 1994; Silveri, Cappa, Mariotti, & Puopolo, 2002). Understanding the profile of words most likely to be learned during a particular point in one's development offers a glimpse of the kind of mind with which one is dealing.

One limitation of our methodology is that it involved linguistic databases of individual words and thus did not take into account words in particular syntactic or larger prosodic contexts (e.g., Friederici, 2005; Gleitman, 1990). For instance, an additional and potentially important variable toward predicting AoA could be frequency norms developed from child-directed speech corpora (e.g., see Bannard & Matthews, 2008; Huttenlocher, Vasilyeva, Waterfall, Vevea, & Hedges, 2007), which could help determine the influence of word frequency within a dyadic parent–child interaction. Input matters, but it is important to stress that input is dynamic because locally language is dyadic. Parents may speak to their children with highly imageable words, but it seems likely that this is not a random choice on their part. Parents (in a dyadic exchange) would seem best to adopt strategies to which children are generally receptive in the first place, and this is species-wide and not something discovered on a child-by-child basis. Neither child-directed speech nor the developing child's receptive mind exists in isolation of one another. We do not, thus, believe that AoA is simply a proxy for the kinds of words that adults use in talking to children of different ages. Child-directed speech changes over time in a predictable way because the children themselves are changing in a predictable way. It is also important to note in this light that our analyses can extend well beyond the initial stage of breaking the word barrier, in which adults may tailor speech to children, and into adulthood and older adulthood. In fact, we propose the feasibility of taking ''snapshots'' of the mind throughout lifespan cognitive development.

Our prediction of the age of a word's acquisition could have benefited from considering more social–pragmatic contributions to word learning (e.g., theory of mind, gaze; Baldwin et al., 1996; Brooks & Meltzoff, 2008; Tomasello, 2005). Indeed, it is hardly surprising that our models do not account for 100% of the variance of the age of a word's acquisition. Individual differences in child-directed input (Huttenlocher et al., 2007) and a family's socioeconomic background (Raizada et al., 2008) exist and are also likely to contribute much to the story of word learning. We acknowledge this important contribution to an individual's word learning. Methodologically and statistically speaking, much in the way of individual differences would be treated as noise in these kinds of analyses, and further research is required to establish the predictive validity of such additional factors for AoA. Nevertheless, that general profiles in the characteristics of words to which children differentially attend actually stand out despite our initial analyses is all the more impressive and encouraging for this methodology.

We believe that these analyses represent an important early step in modeling the hybrid and dynamic nature of word learning. For example, one could bracket out the percentage of variance accounted for at different age ranges in our study and then examine the relative contributions of prosodic, syntactic, and social interaction contexts to the remaining variance, as well as determine how those relative contributions may themselves change over time. As Bloom (2000) noted, word learning occurs in the context of a variety of other interests in a child's mental life. Thus, by examining those factors that predict word learning over time, we may also come to understand those biases and interests of the child and later adult. We argue that the present analyses provide support for a dynamic, hybrid account of word learning in which children are differentially attuned to factors at different points in their development.

Importantly, a multivariate methodology based on linguistic corpora such as the one we introduce here can provide an effective way to test theoretical predictions by guiding the construction of computational models that mimic the language learner, which can be used to corroborate previous experimental findings and to predict new experimental data with both children and adults. This approach, unfortunately not commonly applied to modeling research on language learning, may encourage an integrative dialogue among researchers of AoA, computational modeling, development, and the neuroscience of learning (see Meltzoff, Kuhl, Movellan, & Sejnowski, 2009). In addition, such an approach may inform the construction of novel words that are used as stimuli on developmental studies of language comprehension (e.g., Herold, Nygaard, Chicos, & Namy, 2011; Markman & Wachtel, 1988; Waxman & Markow, 1998). Finally, we believe that there is great promise in applying the same logic to research on second-language acquisition as well as research on the degradation of language or cognitive abilities in older adults (e.g., by using the age of competence x as a dependent variable changing over time in a similar manner to how AoA was treated in the present study). Although the code for language may be broken early in a child's life, word learning is a lifelong process. By studying the differences in cognitive ''snapshots'' taken during early childhood, adolescence, adulthood, and older adulthood, one may be able to understand better the difficulties one encounters when learning a new language, acclimating to a new culture, changing jobs, or tackling social media, as well as develop programs for their mastery.

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