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Short article

The effects of age of acquisition and frequency trajectory on object naming: Comments on Pérez (2007)

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Pérez (2007) reported that objective age of acquisition (AoA) was a major determinant of adult object naming latencies when frequency trajectory and cumulative frequency were included in the same regression analysis. In this comment, we discuss several issues concerning the influence of frequency trajectory and AoA and argue that objective AoA is a behavioural outcome and a natural covariate of frequency trajectory. Bonin, Barry, Méot, and Chalard (2004) argued that the critical test of age-limited learning effects is finding an effect of frequency trajectory when AoA was not included as a factor. This critical test was lacking in Pérez's (2007) study, but several re-analyses of his data show that frequency trajectory is a reliable predictor of naming speed when objective AoA is not included in the regression. We conclude that frequency trajectory remains an important independent variable for the study of the effects of age-limited learning.

Keywords: Picture naming; Age of acquisition; Objective frequency.

In the study of the factors that affect lexical processing, a considerable debate has arisen concerning the respective roles of the age of acquisition and frequency of words (for reviews, see Johnston & Barry, 2006; Juhasz, 2005). In the study of the characteristics of words that affect object naming, the role of age of acquisition (henceforth AoA) has come to be generally accepted. However, an important issue that permeates all studies of AoA effects concerns how AoA is to be measured and conceptualized. In this article, we wish to consider these general issues in relation to the recent object naming study in Spanish by Pérez (2007). We report some re-analyses of Pérez's data and relate these results to the broader methodological and theoretical questions we considered in an earlier paper (Bonin, Barry, Méot, & Chalard, 2004). In particular, we examine the concept and role of *frequency trajectory* as championed by Zevin

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and Seidenberg (2002) for investigations of the effects of age-limited processing.

Studies of AoA effects have used one of three main measures. First, many studies have used adult ratings of when words are acquired (for a recent example, see Cortese & Khanna, 2007). Although adult ratings correlate with more objective measures of the age when words are used and understood (e.g., Jorm, 1991), they may well be contaminated by judgements of general word processing ease, which complicates theoretical interpretations of their effects (see Barbarotto, Laiacona, & Capitani, 2005). Second, more recent studies have used so-called objective measures of AoA based upon when children can produce object names. For example, Morrison, Chappell, and Ellis (1997) discovered the age when 75% of children in 6-month age bands could name a set of pictures; a similar procedure was used by Chalard, Bonin, Méot, Boyer, and Fayol (2003) for French and by Pérez and Navalón (2005) for Spanish. Although these AoA measures are likely to provide more direct estimates of the order of acquisition of words than adult ratings, Zevin and Seidenberg (2002) have seriously questioned their value. They argued that the age at which children can produce object names is an outcome or a performance variable, and so should not be used as a genuine independent variable to predict adult naming performance. Zevin and Seidenberg stressed that the real AoA of a word is a behavioural event, and, in considering the fundamental theoretical issue of why some words are acquired earlier than others, they offered the notion of frequency trajectory as both a measure of AoA and an explanatory concept of its effects.

They suggested that some words are acquired earlier than others because they are encountered more frequently early in life. Some words (e.g., *dragon*, *potty*) occur quite commonly during childhood and less frequently in adulthood; these have a high-to-low frequency trajectory and so will be acquired early. In contrast, other words (e.g., *tax*, *fax*) occur commonly in adulthood but are much less frequent in childhood; these have a low-to-high frequency trajectory and so will be acquired later. There are also words with flat trajectories, whose frequencies are high (or low) in childhood and remain high (or low) in adulthood. It is important to stress that frequency trajectory cannot simply be substituted for AoA, which, as a behavioural outcome, may be affected by many factors; frequency trajectory is a variable that has a causal influence on the age at which words are acquired.

In their connectionist model of word reading, Zevin and Seidenberg compared words with high-to-low and low-to-high frequency trajectories that were matched for cumulative (or total) frequency and found no processing advantage for the "early" items. Furthermore, Zevin and Seidenberg (2004) found that frequency trajectory had no effect on participants' oral reading latencies, although there was a strong effect of cumulative frequency. Bonin et al. (2004) examined frequency trajectory effects in a range of tasks and found that it had no reliable effect on word reading and spelling times, but that it did affect lexical decision and object naming times.

Pérez (2007) reported the results of a study of the variables that affect object naming times in Spanish. His multiple regression analyses found that objective AoA was the main predictor, and that there were also significant effects of cumulative frequency, image agreement, image variability, and neighbourhood density. There was no significant effect of frequency trajectory. To quote the title of his paper, Pérez concluded that "age of acquisition persists as the main factor in picture naming when cumulative word frequency and frequency trajectory are controlled" (p. 32). The critical feature of Pérez's results on which we wish to comment was that he found an effect of objective AoA but not of frequency trajectory when *both* these variables were included in his regression analysis. We submit that the critical test of age-limited learning effects in lexical processing is the demonstration that there is an effect of frequency trajectory when other AoA measures are *not* included in the regression model (see Bonin et al., 2004). This critical analysis was not included in Pérez's (2007) study but is reported below (on the data provided by Pérez). Our argument is

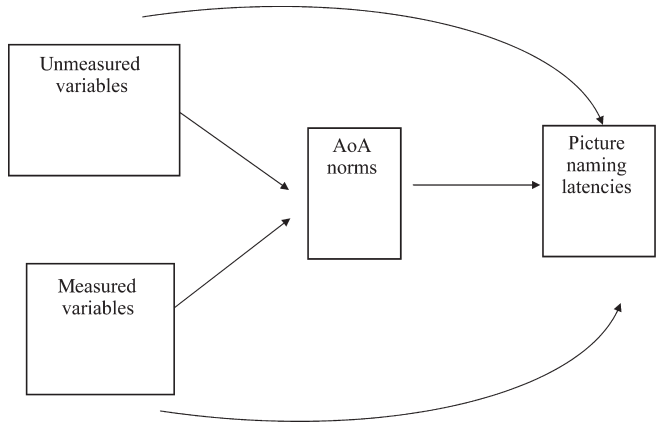

Figure 1. *Age-of-acquisition as a mediator variable.*

that both objective AoA measures and AoA ratings will be determined by a number of factors in addition to the actual age or order of when words are learned, and it is this multiple determination that complicates their use in multiple regressions. We agree with Zevin and Seidenberg (2004) that "it is very difficult to dissociate the effects of when a word was learned (AoA) from the factors that determined when it was learned" (p. 31), factors that also affect skilled performance. If an effect of objective AoA scores is found on the speed (and/or accuracy) of lexical processing in a regression model, it is possible that some of this will be due to factors other than when the actual age or order of when words are acquired. Frequency trajectory is more likely to be a direct measure of the actual order of acquisition, and any effects of this variable should be less likely to be due to other—or mediator—factors (see Figure 1).

Our first series of multiple regression analyses, which did not include objective AoA, were performed including all the predictors (i.e., frequency trajectory, cumulative frequency, name agreement, neighbourhood density, image agreement, object familiarity, visual complexity, and image variability) that were described by Pérez (2007) as potentially important to take into account and not only those he found to be reliable in the best regression model he obtained (see his Table 3, p. 38).[1] The analyses were performed on both naming times and objective AoA scores as the dependent variables. When objective AoA scores were used as the dependent variable, we included predictors that are specific to the pictures (i.e., name agreement, image agreement, visual complexity) because a picture naming task was used with children to derive AoA. We are aware that these factors are highly unlikely to influence the order of acquisition of object names more generally, but we included them in order to avoid the attribution of more variance to factors that are related to the characteristics of the object names (and also to diminish the error variance). (It is worthy of note that Morrison et al., 1997, did the same when predicting objective AoA scores.)

An important question concerns the procedure for computing frequency trajectory and cumulative frequency. Zevin and Seidenberg (2004) used the Zeno (1995) corpus, which provides frequency norms at different ages (grades) including adulthood, and computed cumulative frequency as the *sum* of the frequencies over ages, and frequency trajectory as the *difference* between the sum of

[1] When only the reliable predictors obtained by Pérez (2007) were included in the model, the same pattern of results was obtained.

the frequencies over the three latest grades and the sum of the three earliest grades. The situation is different for Spanish and French because there are separate norms for the earliest grades (1–6 in Spanish and 1–5 in French) and for adults. Since the corpora used to establish child and adult norms are not the same, Bonin et al. (2004) used *z*-scores; frequency trajectory was computed as the difference between the *z*-scores of the (log-transformed) adult and child frequency counts, and cumulative frequency was computed as the sum of these *z*-scores. Using *z*-scores has the advantage of reflecting the relative position of the frequencies of the words in childhood and adulthood as the basis of computations. This procedure ensures that equal weight is given to the two (child and adult) frequency norms and so avoids problems linked with the different size of the corpora used to establish the norms. It also ensures that the cumulative and frequency trajectory measures are uncorrelated, which allows greater statistical power in regression analyses. Pérez (2007) used the same logic in his calculation of frequency trajectory,[2] but he did not use *z*-scores in his computation of cumulative frequency; he directly summed the adult and child frequency measures and then log-transformed this sum. Examination of child and adult frequencies in Spanish (in data reported at http://www.um.es/docenia/maPérez/publications.html) reveals that the mean child frequency is twice the adult frequency. As a result, child frequency is over-represented in Pérez's measure of cumulative frequency. Furthermore, Pérez does not ensure that cumulative frequency and frequency trajectory scores are uncorrelated, which reduces the power of the statistical tests in multiple regression analyses. However, we performed our re-analyses using both Pérez's and Bonin et al.'s procedures for computing cumulative frequency. The results were nearly the same, except that with Bonin et al.'s procedure a little bit more variance was explained. For the sake of clarity, we present only the reanalyses using Bonin et al.'s procedure. Indeed, the existence of different methods of computing cumulative frequency should not distract readers from the general issue concerning the role of objective AoA.

Table 1. *Results of the regression analyses with naming times and age of acquisition (AoA) as dependent variables*

	NT		*AoA*	
	$R^2 = .414$		$R^2 = .408$	
	β	p	β	p
FreqTraj	.204	.002	.382	.0001
CumFreq	−.351	.0001	−.421	.0001
NameAg	.151	.020	.130	.049
PhonN	−.143	.031	.009	.895
ImAg	−.212	.002	−.032	.647
Fam	−.145	.053	−.038	.618
VisComp	−.061	.396	.044	.545
ImVar	−.243	.001	−.132	.077

Note: NT: naming times. FreqTraj: frequency trajectory; CumFreq: cumulative frequency; NameAg: name agreement (H scores); PhonN: number of phonological neighbours; ImAg: image agreement; Fam: object familiarity; VisComp: visual complexity; ImVar: image variability. The minimum tolerance score between IV was .693.

Table 1 shows that both naming latencies and objective AoA scores were reliably predicted by frequency trajectory.

Concerning objective AoA scores, it might be asked whether it is the frequency trajectory of the words per se that is likely to influence their age/order of acquisition or the frequency of the words during childhood irrespective of the subsequent changes in frequency over time. An analysis has been run and suggests that the latter may be the case. However, we did not consider directly child and adult frequency in the regression

[2] A close examination of Pérez's *z*-score computation revealed a potential drawback. He computed standardized *z*-scores of (log) frequencies using the whole Spanish database of child and adult frequencies instead of relying on the sample information. The result was that frequency trajectory was computed by including external information from the sample, while other variables, and more particularly cumulative frequency, used only the information given by the item's sample. The analyses reported used *z*-scores computed from the information provided in the sample.

analyses for two reasons: First, we think that it is important to control for cumulative frequency when predicting naming latencies. As cumulative frequency is indeed equivalent to the first factor of a principal component analysis performed on child and adult frequencies, the high correlation of cumulative frequency with child frequency makes it problematic to use these two variables as predictors in a regression analysis with naming latencies as the dependent variable. The same problem arises if we include adult frequency and child frequency—instead of cumulative frequency and frequency trajectory—as independent variables in a regression analysis to predict naming latencies: since these two factors are highly correlated (.791), the outcome is that the tests may become very conservative. (We have performed such an analysis, which showed that there was no reliable effect of adult frequency but a reliable effect of child frequency. It cannot be excluded that adult frequency in this analysis was not significant simply because the test had a low statistical power.) Second, frequency trajectory provides information concerning the way words have been encountered during childhood as against adulthood for a given level of cumulative frequency.

A second analysis was performed on naming latencies with the independent variables of frequency trajectory, cumulative frequency, objective AoA, and the other predictors that were reliable in Pérez's (2007) analyses.[3] Table 2 shows that objective AoA was the most important reliable predictor of naming times in this analysis. This analysis revealed that frequency trajectory was not significant when objective AoA was also included. Actually, this was exactly the same result as found by Bonin et al. (2004; see their Table 6, p. 465) using a different set of predictors.

Finally, we repeated the second regression analysis but this time excluding objective AoA. Such an analysis was not reported by Pérez (2007), but, as we have argued above, it represents the critical test for determining whether there is an effect of frequency trajectory. Table 3 shows that frequency trajectory was a reliable predictor of naming latencies.

Table 2. *Results of the regression analyses with naming times as the dependent variable and objective AoA, frequency trajectory, cumulative frequency, and other reliable predictors in Pérez's analysis as independent variables*

	$R^2 = .475$	
	β	p
FreqTraj	.047	.48
CumFreq	− .223	.003
AoA	.395	.0001
ImAg	− .206	.001
ImVar	− .195	.003
PhonN	− .139	.027

Note: CumFreq: cumulative frequency; FreqTraj: frequency trajectory; AoA: age of acquisition; ImAg: image agreement; ImVar: image variability; PhonN: number of phonological neighbours. The minimum tolerance coefficient was .613.

The results of these re-analyses of Pérez's (2007) data are very similar to those reported by Bonin et al. (2004) for oral object naming times. They found that objective AoA was significant when frequency trajectory and cumulative frequency were also included in the regression. However, unlike Pérez, Bonin and colleagues did not conclude that AoA was the main determinant of naming time. As objective AoA is derived from children's naming performance, it is a behavioural outcome, and so it is not surprising that it is closely related to adult naming behaviour. Also, the strong relationship between objective AoA and naming latencies is due to the fact that in most studies (e.g., Chalard et al., 2003; Pérez, 2007) the same task is used both to derive objective AoA scores and to measure naming speed—that is, picture naming! Bonin and co-workers argued that the critical test of age-limited learning effects on object naming would be to demonstrate a reliable effect of frequency trajectory when objective AoA is not included in the regression analysis (see also Zevin & Seidenberg, 2004). Frequency trajectory, which is an objective, truly independent

[3] The same analysis performed with cumulative frequency using Pérez's procedure showed essentially the same patterns.

Table 3. *Results of the regression analyses with naming times as the dependent variable and frequency trajectory, cumulative frequency, and other reliable predictors in Pérez's analysis—but not objective AoA—as independent variables*

	$R^2 = .380$	
	β	p
FreqTraj	.199	.002
CumFreq	−.404	.0001
ImAg	−.231	.0001
ImVar	−.242	.001
PhonN	−.134	.046

Note: CumFreq: cumulative frequency; FreqTraj: frequency trajectory; Freq: adult or cumulative frequency, depending on the column referred to; ImAg: image agreement; ImVar: image variability; PhonN: number of phonological neighbours. For all IV, the minimum tolerance coefficient was .82.

variable, does have an effect when AoA is not included in the regression both in Bonin et al. (2004) and in the present re-analyses of Pérez's (2007) data. It might be argued that frequency trajectory—and, indeed, word frequency—cannot be conceived as objective, true independent variables, since the actual frequencies of the words are determined by the behaviour of human beings (i.e., the people who produce the words to which other people are exposed):[4] it is because people speak, read, or write some words more often than others that they become more frequent. Although it is certainly the case that word frequency is influenced by such "collective" factors, objective AoA scores are characterized as a behavioural outcome because the way it is measured directly depends on the performance of participants (naming accuracy in children, ratings in adults), whereas word frequency is derived from the analyses of corpora: it is the number of times a word is found in a corpus.

An examination of Tables 2 and 3 reveals that the percentage of variance accounted for when objective AoA is not included in the analysis is smaller than when it is included; the difference is about 10%. Although this might, at first glance, suggest that frequency trajectory is not a better candidate variable than objective AoA to study age-limited learning effects, percentage of explained variance accounted for by a factor does not in itself act as "proof" that the factor has a causal influence on the dependent variable. Our thesis is that objective AoA, as a performance measure, mediates the effect of several aspects that are not specifically linked with true age or order of acquisition (see Figure 1). Thus, objective AoA reflects more than just the order of acquisition, and so it is difficult to rely only on explained variance accounted for to justify that it is an independent (and major) determinant of lexical processing.

As the same task is used to provide the independent variable of objective AoA norms and the dependent variable (i.e., picture naming accuracy in children and picture naming times in adults), it is no surprise, from a logical point of view, that certain variables are reliable determinants of both naming time and objective AoA norms. Indeed, objective AoA has an "exceptional" explanatory power for picture naming compared to other lexical tasks. Although AoA effects are predicted to be particularly strong in picture naming, it nevertheless seems quite strange that objective AoA does not have a higher explanatory power than rated AoA or frequency trajectory, for example in lexical decision (see Bonin et al., 2004, Table 9). Moreover, Bonin et al. (2004, Table 6) have shown that several predictors that reliably predict picture naming times (i.e., conceptual familiarity, cumulative frequency, and frequency trajectory) were no more reliable when objective AoA was included as a factor in the regression analyses. (In Pérez's data this property was observed only for frequency trajectory. Other reliable variables were found with and without AoA in the regression analyses. However, given that not all the same independent variables were used by Pérez and Bonin et al., the results are difficult to compare.) Inspection of Bonin et al.'s Table 1 shows that these predictors also have an effect on objective AoA scores. This suggests that objective AoA acts

[4] We thank Andy Ellis for this point.

primarily as a mediator variable. As a result, it is important to rely on frequency trajectory in the analyses, because this has an influence on the order of acquisition of the words and is clearly different from adult frequency. Therefore, it is important to include frequency trajectory in the regression analyses in order to evaluate the effect that corresponds to the proportion of AoA specifically due to frequency (but AoA cannot be reduced to the latter aspect). In our view, since objective AoA norms capture more than the order of acquisition, they are not pure measures of the order of acquisition of the words per se. We think that it is risky to rely on the variance accounted for by objective AoA to argue that the order of acquisition is one the strongest determinants of picture naming latencies (a strong claim made some years ago by Chalard et al., 2003, for instance). This may lead to more weight being given to the order of acquisition factor than is in fact the case.

Within connectionist models of lexical processing (Ellis & Lambon Ralph, 2000; Monaghan & Ellis, 2002; Zevin & Seidenberg, 2002), age-limited learning effects depend upon the degree of consistency of the mapping relationships between input and output. For reading words aloud in English and French, there are quasi-systematic relationships between the input orthographic codes and the output phonological codes. What is learned about items acquired earlier could be used to assist the learning of items acquired later (e.g., knowing the pronunciation of the words *bat*, *cat*, and *hat* would be of help when reading aloud the later-acquired word *vat*). In such circumstances, the network's performance shows no effect of AoA.[5] However, for naming objects, there are essentially arbitrary relationships between the input structural and semantic codes and the output phonological codes: knowing the names of the objects CAT and HAT would not be of help in naming the similar and related objects DOG or CAP. In these circumstances, AoA effects are observed reliably.

It might be argued that some connectionist models account for the effects of age or order of acquisition of items and cumulative frequency without relying on frequency trajectory. Ellis and Lambon Ralph (2000) used a three-layer network that learned by back propagation with cumulative learning. Several simulations showed that the order of introduction of the patterns in the course of learning had a long-term influence on the network's performance, with the result that the network achieved better performance on patterns introduced early than on those introduced later. Analysis of the network's behaviour revealed that when patterns were introduced early in the training, they altered the weights in such a way as to represent themselves, with the result that late patterns had to struggle to represent themselves. Thus, the network was shown to lose plasticity with learning. The frequency of presentation of the patterns also altered the network, with the result that frequently encountered patterns were better encoded than were less frequent patterns. With the type of network used by Ellis and Lambon Ralph (2000), Lambon Ralph and Ehsan (2006) showed that frequency of presentation and order of introduction of the patterns had non-additive effects, especially when the mappings between input and output patterns were arbitrary. However, the kind of interaction exhibited by this kind of network is not observed in behavioural data. Cuetos, Alvarez, González-Nosti, Méot, and Bonin (2006) found additive effects of cumulative frequency and AoA on object naming times. Therefore, connectionist models that learn on the basis of order of introduction of the patterns and their frequency of encounters (Ellis & Lambon Ralph, 2000) do not fully account for the empirical data.

In conclusion, the bulk of empirical evidence supports the claim that both cumulative frequency and frequency trajectory are reliable determinants of object naming speed. The present re-analyses of Pérez's (2007) Spanish

[5] Monaghan and Ellis (2002) found larger AoA effects on naming times for words with inconsistent spelling-to-sound relationships, which supports this general approach.

data are consistent with the results of Bonin et al.'s (2004) analysis of French naming data, and both support the claim advanced by both Zevin and Seidenberg (2002) and Bonin et al. (2004) that when a lexical task engages specific and arbitrary mappings between input and output codes (as is the case in object naming), age-limited learning effects are observed. We conclude that frequency trajectory remains an important independent variable for the study of the effects of age-limited learning, even though until now this approach has not been frequently followed. In the study of age-limited learning effects, the dominant view has been to use rated or objective AoA norms as an independent variable to index the order of acquisition of the words. We are not claiming that the order of acquisition of items does not have a genuine influence upon the processing by mature cognitive systems. Indeed, Stewart and Ellis (2008) have demonstrated experimentally an effect of the order of introduction of new arbitrary perceptual patterns in a categorization task in adults. Interestingly, frequency trajectory of the patterns was manipulated, so that some patterns would be learned early or late (see also Pérez, Izura, Stadthagen-González, & Marín, 2008; Tamminen & Gaskell, 2008).

To reiterate, we do not exclude the possibility that order of acquisition might have a genuine direct influence on adult naming speed, but the way order of acquisition is operationalized is, in our view, problematic, as we have tried to show. To conclude, we hope our contribution will not be viewed as "a target to shoot at", but will stimulate further debate and future work on age-limited learning effects.

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