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Contextual diversity is a main determinant of word identification times in young readers

Manuel Perea [a,*], Ana Paula Soares [b], Montserrat Comesaña [b]

[a] ERI – Lectura and Departamento de Metodología, Facultad de Psicología, Universitat de València, 46010 Valencia, Spain
[b] Human Cognition Lab, CIPsi, School of Psychology, University of Minho, 4710-057 Braga, Portugal

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ABSTRACT

Recent research with college-aged skilled readers by Adelman and colleagues revealed that contextual diversity (i.e., the number of contexts in which a word appears) is a more critical determinant of visual word recognition than mere repeated exposure (i.e., word frequency) (*Psychological Science*, 2006, Vol. 17, pp. 814–823). Given that contextual diversity has been claimed to be a relevant factor to word acquisition in developing readers, the effects of contextual diversity should also be a main determinant of word identification times in developing readers. A lexical decision experiment was conducted to examine the effects of contextual diversity and word frequency in young readers (children in fourth grade). Results revealed a sizable effect of contextual diversity, but not of word frequency, thereby generalizing Adelman and colleagues' data to a child population. These findings call for the implementation of dynamic developmental models of visual word recognition that go beyond a learning rule by mere exposure.

Introduction

Word identification times in laboratory tasks and eye fixation times during normal reading are shorter when reading a word that occurs frequently in print such as *heart* than when reading an infrequent word such as *elbow*. This is the case both in adult readers (e.g., see Balota et al., 2007; Inhoff & Rayner, 1986) and in young readers (e.g., Hyönä & Olson, 1995; Moret-Tatay & Perea, 2011).

Unsurprisingly, word frequency plays a central role in all current computational models of visual word recognition and reading. For instance, in the family of localist activation-based models, the

* Corresponding author.
E-mail address: mperea@valencia.edu (M. Perea).

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resting level of activation of a given word unit depends on its printed word frequency (e.g., spatial coding model: Davis, 2010; dual-route cascaded model: Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; interactive activation model: McClelland & Rumelhart, 1981; multiple read-out model: Grainger & Jacobs, 1996). Likewise, computational models of reading such as the E-Z Reader model (Reichle, Pollatsek, Fisher, & Rayner, 1998) and the SWIFT model (Engbert, Nuthmann, Richter, & Kliegl, 2005) employ a similar mechanism of word frequency during the initial "lexical access" stage.

One obvious shortcoming of these "static" models is that they assume a well-formed and unalterable set of parameters (as in an adult skilled reader) in which word frequency is included as a critical element (see Baayen, 2010, for criticism of these models). Although there is the implicit assumption that the frequency effect has its origin in the repetition effect, these models provide no information about the underlying nature (or locus) of the word frequency effect. Thus, one obvious question is how repeated presentations affect a word's accessibility during the course of word learning in an immature word recognition system (see Acha & Perea, 2008; Wang, Castles, Nickels, & Nation, 2011, for developmental analyses of orthographic effects in visual word recognition).

Is word accessibility merely driven by a count of past presentations (i.e., word frequency)? Recently, a number of theorists have claimed, using large databases collected from college-aged students, that the main determinant of word identification times is not "pure repetition" per se but rather the number of contexts in which a given word occurs (Adelman, Brown, & Quesada, 2006; see also Baayen, 2010; Brysbaert & New, 2009, & Keuleers, Brysbaert, & New, 2010, for similar conclusions). Clearly, words that appear in many contexts tend to be quite frequent in print, and this explains the previous reports of a word frequency effect; they would be obtained because of a confound with the number of contexts in which a word occurs. This latter factor has been named *contextual diversity* and has been defined as "the proportion of texts in which a given word occurs" (Adelman et al., 2006). Adelman and colleagues (2006) indicated that if a given word appears in very different contexts, the likelihood of that word appearing in other contexts increases, and this may facilitate the relative accessibility of these words in the "mental lexicon".

Importantly, contextual diversity has also been claimed to be a relevant factor to word acquisition in developing readers (e.g., see Hills, Maouene, Riordan, & Smith, 2010). Thus, if words that are initially learned in many contexts have more accessible and enriched internal representations than words that are learned in a limited number of contexts, then the effects of contextual diversity should be particularly clear for developing readers. (Note that children's word learning mechanisms may be even more important for word recognition than in the case of the more "stable" word representations in skilled adult readers; see Ratcliff, Love, Thompson, & Opfer, 2012, for evidence of less efficient word processing in children than in college-aged students.)

In the current experiment, we examined the role of contextual diversity and word frequency in word identification times in young readers (children in fourth grade). Unsurprisingly, it was not possible to obtain enough low-frequency words with high contextual diversity, and this latter condition was not included in the experiment. The hypotheses are clear. If mere repeated exposure (and not context diversity) is the driving force in lexical access (as stated in currently implemented computational models), then words that occur frequently in print—while keeping contextual diversity controlled—should produce faster word identification times than words that occur least frequently (i.e., a word frequency effect). Alternatively, if context diversity (and not word frequency) is the driving force in lexical access (as claimed by Adelman and others), then words that occur in many contexts in print—while keeping word frequency controlled—should produce faster word identification times than words that occur in few contexts. If this latter hypothesis is confirmed, then a new conceptualization of models of visual word recognition would be required. This applies to more than just the static activation-based models cited above. Connectionist models (e.g., Plaut, McClelland, Seidenberg, & Patterson, 1996) are dynamic models that include a learning rule (i.e., word learning is possible). However, as noted by Baayen (2010), this learning rule relies on repeated presentations of the words rather than on contextual diversity (i.e., the PDP [parallel distributed processing] model cannot explain the contextual diversity effects reported by Adelman et al., 2006).

Contextual diversity and word frequency were obtained from the ESCOLEX database (Soares et al., 2012). ESCOLEX is a children's lexical database with grade-level word frequency statistics for 6- to 11-year-olds (first to sixth grades) for a total of approximately 48,500 word forms computed from a

3.2-million-word corpus taken from 171 European Portuguese elementary textbooks. Similar to Adelman and colleagues (2006), contextual diversity was computed as the number of textbooks in which a given word appeared, and word frequency was computed as the number of occurrences of a given word (per million words) in the corpus. In the current study, these indexes were collected from first- to fourth-grade computations; the participants were children in fourth grade. All fourth graders were familiar with all the words in print employed in the experiment given that all these words appeared in textbooks of the initial year of primary school.

In the experiment, we used the most popular laboratory word identification task—lexical decision ("Is the stimulus a word?"; e.g., see Dufau et al., 2011). We opted for the go/no-go procedure (i.e., press a key for "word" and refrain from responding for "nonword") because it is the preferable procedure in experiments with children (i.e., it produces faster lexical decision times and fewer errors than the yes/no procedure; Moret-Tatay & Perea, 2011; see Perea, Moret-Tatay, & Panadero, 2011; Perea, Panadero, Moret-Tatay, & Gómez, 2012, for evidence with young readers; see also Gómez, Ratcliff, & Perea, 2007, for a mathematical model of the go/no-go task).

Experiment

Method

Participants

A sample of 22 children in fourth grade (mean age = 9.94 years, range = 9.53–10.52, 11 girls and 11 boys) participated voluntarily in the experiment; written consent had been obtained from their parents. The children came from above-average socioeconomic backgrounds and attended a private school in Porto, Portugal. All participants had normal (or corrected-to-normal) vision and were native speakers of European Portuguese. None of them had any sensory, neurological, or learning disabilities. The experiment took place at the end of the academic year.

Materials

A set of 60 Portuguese words was selected from the ESCOLEX database (Soares et al., 2012). All these words were either nouns or adjectives. The two factors intended in the experiment were contextual diversity (low vs. high) and lexical frequency (low vs. high). (For simplicity, we employ the term *low-frequency words,* but these words would be better qualified as "medium"-frequency words.) Given that it was not possible to obtain enough stimuli in the condition of high contextual diversity and low frequency, this condition was discarded (see Table 1 for the values [averages and ranges] in each condition). For each of the three remaining conditions (i.e., high contextual diversity–high frequency, low contextual diversity–high frequency, and low contextual diversity–low frequency), there were 20 words each that were well matched in imageability, concreteness, familiarity, number of letters, number of syllables, and number of orthographic neighbors in the ESCOLEX database (see Table 1) (all *ps* > .17). A set of 60 orthographically legal pseudowords—matched in word length with the word

Table 1
Characteristics of words employed in the experiment.

	IMG	FAM	CONC	# Letters	# Syllables	DC	FRQ_MIL	N
High CD–high frequency	4.55 (2.3–5.8)	6.59 (6.3–6.8)	4.74 (2.6–6.6)	5.65 (4–8)	2.55 (2–3)	0.65 (0.6–0.8)	202.85 (154–289)	2.90 (0–8)
Low CD–high frequency	4.51 (3.0–5.8)	6.50 (6.2–6.8)	4.90 (3.6–6.6)	5.85 (5–7)	2.55 (2–3)	0.33 (0.2–0.4)	202.04 (112–402)	1.45 (0–11)
Low CD–low frequency	4.63 (3.2–5.7)	6.56 (6.2–6.9)	4.95 (3.4–6.2)	5.85 (5–7)	2.75 (2–3)	0.32 (0.2–0.5)	53.22 (25.5–69.4)	2.00 (0–9)

Note: Ranges are in parentheses. IMG, imageability (1–7); FAM, subjective familiarity (1–7); CONC, concreteness (1–7); # Letters, average number of letters; # Syllables, average number of syllables; DC, proportion of textbooks that include the target word in the ESCOLEX database; FRQ_MIL, frequency per million in the ESCOLEX database; N, number of orthographic neighbors in the ESCOLEX database (i.e., Coltheart's *N*); CD, contextual diversity.

stimuli—was created for the purposes of the lexical decision task. A list of the words and pseudowords is presented in the Appendix.

Procedure

The experiment took place in groups of 4 children in a quiet room. DMDX software (Forster & Forster, 2003) was used to present the stimuli and collect the responses. The scheme of a given trial was as follows. A fixation point (+) was presented for 500 ms in the center of the screen. Then, the stimulus (either a word or a nonword) was presented in lowercase 14-point Times New Roman font. The word/nonword remained on the screen until the participant responded or 2500 ms had elapsed. The intertrial interval was 1 s. Participants were told that real words and "nonsense" words would be displayed on the computer screen and that they should press one button (labeled *sim* [yes]) if the stimulus was a real word and should refrain from responding if the stimulus was not a real word. Participants were instructed to respond as fast as possible while trying not to make too many errors. Each participant received a different random order of stimuli. The session lasted approximately 10 min.

Results

Incorrect responses and response times less than 250 ms or greater than 1500 ms (3.1% of data) were excluded from the latency analysis. The mean response times for correct responses and the error rates per condition are presented in Table 2. Error rates for word stimuli were very low (<0.5%) and were not further analyzed.

Because of the characteristics of the experimental design (i.e., absence of the high contextual diversity–low frequency condition), we conducted planned comparisons on the lexical decision data rather than an unfocused omnibus analysis (see Wilcox, 1987). First, to examine the effect of contextual diversity, we compared the condition with low contextual diversity–high frequency versus the condition with high contextual diversity–high frequency. Second, to examine the effect of word frequency, we compared the condition with low contextual diversity–high frequency versus the condition with low contextual diversity–low frequency. These planned comparisons were based on the participant (t_1) and item (t_2) mean correct response latencies.

Effect of contextual diversity

On average, words with a high contextual diversity were responded to 53 ms more rapidly than words with a low contextual diversity, $t_1(21) = 3.37$, $SE_{\text{dif}} = 15.6$, $\eta^2 = .35$, $p = .003$; $t_2(38) = 2.89$, $SE_{dif} = 18.0$, $\eta^2 = .18$, $p = .006$.

Effect of word frequency

The difference between the identification times of low- and high-frequency words was less than 2 ms (both $|t|$s < 1).

Similar to Adelman and colleagues (2006), and to further examine the impact of contextual diversity and word frequency on lexical decision times in developing readers, we conducted a regression analysis in which response time was the dependent variable and $\log_{10}$ of contextual diversity and $\log_{10}$ of word frequency (both from ESCOLEX database), number of letters, and imageability were used

Table 2
Mean lexical decision times (in ms) and percentages of errors (in parentheses) for words in the experiment.

Word frequency	Contextual diversity	
	Low	High
Low	808 (0.2)	
High	807 (0.9)	754 (0.2)

Note: The error rate for pseudowords was 6.7%.

as predictions. The regression analysis indicated a facilitative effect of $\log_{10}$ of contextual diversity ($\beta = -.41$, $t = -3.15$, $p = .003$) and imageability ($\beta = -.31$, $t = -2.67$, $p = .01$), but not of $\log_{10}$ of word frequency ($\beta = -.04$, $|t| < 1$, $p > .50$), whereas the number of letters had a (nonsignificant) inhibitory trend ($\beta = .17$, $t = 1.47$, $p = .15$). Thus, the regression analyses confirmed the importance of contextual diversity in visual word recognition with young readers.

Replication study

Given the implications of the current findings for developmental dynamic models of visual word recognition, it is important to reexamine the effects of contextual diversity and word frequency using another set of words and another sample of young readers. Because both word frequency and contextual diversity are continuous variables, we selected 60 words widely differing in these factors and conducted a regression analysis parallel to that conducted above. We employed a go/no-go lexical decision task.

Method

Participants

The participants were 27 fourth graders from the same school as in the reported experiment; written consent had been obtained from their parents. They had not participated in the previous experiment.

Materials

We selected a set of 60 European Portuguese words (nouns and adjectives) varying in word frequency ($M = 215$ per million, range = 43–934) and contextual diversity ($M = .48$, range = .10–.85 in the ESCOLEX database). We also created a set of 60 orthographically legal pseudowords for the purposes of the lexical decision task. A list of the items is provided in the Appendix.

Procedure

We used the same procedure as in the previous experiment.

Results

Error responses (1.4%) and response times less than 250 ms or greater than 1500 ms (4.3%) were excluded from the response time analysis. The predictors of the latency data were the same as in the regression analysis reported above. Results again indicated a facilitative effect of $\log_{10}$ of contextual diversity ($\beta = -.37$, $t = -2.96$, $p = .005$) and imageability ($\beta = -.30$, $t = -2.61$, $p = .01$), but not of $\log_{10}$ of word frequency ($\beta = -.15$, $t = -1.24$, $p = .22$). As in the experiment, the effect of number of letters was slightly inhibitory ($\beta = .19$, $t = 1.87$, $p = .067$).

General discussion

The current study, using two sets of words, has revealed that contextual diversity is a main determinant of word identification times in young readers, thereby generalizing the data from Adelman and colleagues (2006) with college-aged participants to a child population—and a different language (Portuguese). Furthermore, and similar to Adelman and colleagues' analyses, word frequency did not determine word identification times, at least in the range of frequencies (i.e., medium–high frequency) employed in the current study.

The current data pose obvious problems for static models of visual word recognition that assume that "word frequency" per se plays a key role—particularly when applying these models to a child population. Future implementations of computational models of visual word recognition should go beyond static word representations and include a learning rule. This learning rule should not just work on the basis of mere count of instances in which a word appears because the more contexts in which a word is presented, the faster its identification—all other things being equal. Of particular interest here is the semantic distinctiveness (SD) model proposed recently by Jones, Johns, and Recchia (2012). In the context of word acquisition, the repetition of a word in the SD model produces a detectable modification in a word's memory strength only when it is accompanied by a change in context. This context can be regarded at a global level (as proposed by Adelman et al., 2006) or at a more local level (on the basis of similarity-based models of word co-occurrence; Hoffman, Rogers, & Lambon Ralph, 2011; McDonald & Shillcock, 2001; see also Landauer & Dumais, 1997). The current study was not designed to distinguish between these options. Further research with developing readers should help to separate the importance of these two approaches.

The current developmental data have implications for models of memory, in particular, on the area of literacy and word acquisition—in the context of learning both a first language (L1) and a second language (L2). The current findings, in conjunction with previous research (e.g., Hills et al., 2010; Jones et al., 2012; Steyvers & Malmberg, 2003), reveal that in order to facilitate literacy skills, words should be learned in different contexts. Thus, from an educational point of view, and in the context of word learning (e.g., in a second language), the current data suggest that teachers should provide learning opportunities so that the same word can be experienced in different contexts of occurrence rather than confronting developing readers with repeated presentations of words (e.g., nouns, adjectives) in very specific (or similar) contexts.

In sum, we have demonstrated, across two samples of words, that the effect of contextual diversity in visual word recognition is robust in developing readers. This strongly suggests that a dynamic context-dependent approach to word acquisition should be included in future implementations of models of visual word recognition. At an applied level, the current data can also have practical implications on the way new words (in L1 or L2) are initially learned and accessed.

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Appendix A. Experiment

List. of words

High. contextual diversity–high frequency

balão; longo; passeio; certo; altura; música; igual; barco; direita; frente; campo; viagem; dinheiro; bonito; modo; animal; leite; cabeça; falta; final

Low. contextual diversity–high frequency

ficha; plural; bloco; poema; metro; dezena; sujeito; divisão; litro; raposa; vírgula; nuvem; autor; manual; macaco; sonho; cálculo; carta; segredo; produto

Low. contextual diversity–low frequency

código; corrida; almoço; escuro; parede; ouvido; pedaço; modelo; tecido; braço; mágico; moinho; doente; pinhal; desejo; minuto; regra; dente; curto; buraco

List. of pseudowords

anve; riafe; lasbo; gisbo; nasma; tenfo; vilno; tapra; grica; malpa; borvo; danba; rilba; tarlo; vesca; racla; panto; grica; cuefo; ludia; etura; dusle; gasva; upesta; mislos; nafeta; dunibo; balver; dalpar;

cormas; cetupa; anerbo; coltor; culfos; levrol; nosfeu; untipa; triego; muelfo; dipada; adisgo; guinle; denvas; canbra; iselas; verfes; lirato; libaza; forvas; dunfol; dorelta; moltroa; ristura; tengala; corlufa; pábiras; esdutos; rocerço; norjada; canfresa

Appendix Replication. study

List. of words

fruto; irmão; festa; melhor; campo; leite; autor; tarde; balão; lápis; planta; porta; manhã; rapaz; praia; mensal; cento; litro; quadra; milhar; painel; régua; metro; plural; banda; verbo; costa; verso; triste; ficha; carro; longo; falta; jornal; certo; regra; conta; cheio; barco; banho; velho; pinta; turma; frente; quinta; pastor; prosa; museu; corvo; local; grilo; grave; pinhal; bloco; pobre; barro; braço; monte; gente; guarda

List. of pseudowords

demor; garlu; traquo; conci; tenoi; lanhi; lisna; tonpo; fotru; quarro; conbra; varla; renhos; tinve; riafe; balver; trome; danba; borvo; pazca; merno; falni; mumco; tenfo; tantri; lasbo; zarão; rilba; donli; uvnem;; panti; tocur; fotei; rizna; dajau; janla; nasma; molti; tuala; gavem; dinceu; galmi; tosas; deida; neira;; cranba; volme; nector; guaia; tapra; malpa; dalpar; peton; marpo; panto; topre; sotal; reifa; mopri; tonsa

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