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Brief Report

Do young readers have fast access to abstract lexical representations? Evidence from masked priming

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ABSTRACT

Although there is consensus that adult readers have fast access to abstract letter/word representations, the developmental trajectory of such access has not been mapped out yet. To examine whether developmental readers have rapid access to abstract representations during the early stages of word processing, we conducted a masked priming lexical decision experiment with two groups of young readers (third and fifth graders) and a group of young adults. We selected two types of words: (a) words composed of cross-case letters that are visually dissimilar (DIS words; e.g., arte/ARTE [Spanish for *art*]) and (b) words composed of cross-case letters that are visually similar (SIM words; e.g., vivo/VIVO [Spanish for *alive*]). For young adults and fifth graders, response times for DIS and SIM words were very similar in the matched- and mismatched-case identity priming conditions, which in turn produced shorter responses than the unrelated condition (i.e., ARTE–ARTE = arte–ARTE < edad–ARTE). This is consistent with the idea that there is fast access to abstract representations. In contrast, this process does not seem to be fully operative in third graders, as revealed by the pattern of data with DIS words (ARTE–ARTE < arte–ARTE = edad–ARTE). These findings have relevant implications for developmental models of visual word recognition and for the use of masked priming experiments with developmental readers.

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Introduction

While reading, the brain rapidly maps a visually dissimilar input (e.g., edge and EDGE) onto a common abstract lexical representation. The dominant accounts of printed word recognition in alphabetic orthographies assume that access to a visual word form in adult readers is attained via the activation of abstract letter units (ALUs) in the ventral areas of the brain (Dehaene, Cohen, Sigman, & Vinckier, 2005; Grainger, Rey, & Dufau, 2008; see Coltheart, 1981, for early evidence of the existence of ALUs). Compelling empirical evidence of the rapid activation of abstract representations during printed word recognition comes from masked priming experiments in adults. This paradigm taps the early stages of word processing via the presentation of a briefly presented masked prime (see Grainger, 2008, for a review). In a masked priming lexical decision experiment, Jacobs, Grainger, and Ferrand (1995) compared case-mismatched versus case-matched identity word pairs (YEUX–####–YEUX vs. yeux–####–YEUX; [eyes]) and found that, despite the greater visual similarity for the matched-case identity pairs, word identification times were virtually the same in the two conditions. Perea, Jiménez, and Gómez (2014) replicated Jacobs et al. (1995) pattern in words with high cross-case visual similarity (henceforth SIM words; e.g., city–###–CITY produced the same word identification times as CITY–###–CITY) and in words with low cross-case visual similarity (henceforth DIS words; e.g., edge–###–EDGE produced the same word identification times as EDGE–###–EDGE). Furthermore, similarly to Bowers, Vigliocco, and Haan (1998), Perea et al. (2014) found that the advantage of the identity priming condition relative to an unrelated condition was remarkably similar for SIM and DIS words (see Kinoshita & Kaplan, 2008, for a parallel finding with pairs of cross-case visually similar and visually dissimilar letters in masked priming).

The developmental trajectory of the access to abstract representations has not yet been mapped out. How does a developmental reader associate a common abstract representation with visually dissimilar stimuli such as edge and EDGE? Jackson and Coltheart (2001) hypothesized that ALUs are acquired when children are able to name the letters in uppercase and lowercase forms. ALUs would become available when children start to establish orthographic representations of words (e.g., as postulated by Ehri's (1999) model). Note, however, that Jackson and Coltheart (2001) acknowledged that these abstract representations might not be as efficiently accessed for developmental readers. An alternative view was proposed by Polk et al. (2009). They proposed that letters that have cross-case visual similarity (e.g., c/C) would form a context for the letters that have cross-case visual dissimilarity (e.g., r/R). Hence, when a printed word appears in some occasions in uppercase form and in other instances in lowercase form, the cognitive system creates ALUs for letters in different case because the visual contexts are similar. The current experiment was not designed to disentangle the Jackson and Coltheart versus Polk and colleagues hypotheses; rather, it was designed to examine, in a masked priming experiment, if and when young readers can rapidly activate abstract representations during the earliest stages of word processing. Indeed, in a review on how children acquire abstract letter units, Thompson (2009) concluded that "the acquisition of ALUs takes a developmentally long learning route" (p. 67).

For the current experiment, we selected two types of words: (a) words composed of cross-case letters that are visually dissimilar (DIS words; e.g., arte/ARTE [Spanish for *art*]) and (b) words composed of cross-case letters that are visually similar (SIM words; e.g., vivo/VIVO [Spanish for *alive*]). As in Jacobs et al. (1995) and Perea et al. (2014) experiments, the key comparison was between the matched-case and mismatched-case identity primes (i.e., ARTE–####–ARTE vs. arte–####–ARTE; VIVO–####–VIVO vs. vivo–####–VIVO). An unrelated priming condition was included for comparison purposes. If young readers have rapid access to abstract letter/word representations, word identification times should be similar for matched-case and mismatched-case identity pairs. (Note that this should be the case not only with SIM words [e.g., vivo–VIVO vs. VIVO–VIVO] but also with DIS words [e.g., arte–ARTE vs. ARTE–ARTE].) Alternatively, if young readers do not have rapid access to abstract letter/word representations, responses to DIS words should be faster when preceded by a matched-case identity prime than when preceded by a mismatched-case identity prime (i.e., ARTE–ARTE faster than arte–ARTE). Furthermore, under these circumstances, the advantage of the mismatched-case identity priming condition over the unrelated condition might be small or negligible.

Understanding the developmental trajectory has implications for the interpretability of masked priming experiments with young readers. Previous masked priming experiments with children have implicitly assumed that the processing of the prime stimuli operates similarly in children and adults. If, contrary to this assumption, younger readers do not activate abstract representations from the prime during the very early stages of word processing, masked priming effects would be based mostly on the visual similarity between prime and target. This point is relevant because a number of recent experiments have tracked developmental changes by comparing children of different ages (around third and fifth grades) using the masked priming technique (e.g., Acha & Perea, 2008; Castles, Davis, Cavalot, & Forster, 2007; Lété & Fayol, 2013). If there is an advantage of EDGE–####–EDGE over edge–####–EDGE in Grade 2/3 readers but not in Grade 4/5 readers, one must be cautious when interpreting any differences in masked priming across groups.

Three groups of participants were included in the experiment: third graders, fifth graders, and adults. Fifth graders have the experience to have relatively fast access to lexical information compared with third graders (see Castles et al., 2007), and they may efficiently use abstract representations. There is some evidence that suggests the use of abstract cues rather than visual cues during lexical access in fourth or fifth grade. For instance, Perea and Panadero (2014) recently reported, in a single-presentation lexical decision experiment with fourth graders at the end of the academic year, that the response times (and error rates) to pseudowords were virtually the same regardless of whether the mismatching letter was visually similar to the critical letter in the base word or not (e.g., viotin vs. viocin; the base word is *violin*); indeed, only the children with dyslexia were sensitive to the effects of visual similarity.

We employed the go/no-go variant of the lexical decision task (i.e., respond to “words” and refrain from responding to “nonwords”) rather than the yes/no variant because the go/no-go procedure is more appropriate for young readers (see Davis, Castles, & Iakovidis, 1998; Perea, Soares, & Comesaña, 2013). Because of the restrictions at selecting the stimuli (i.e., words known by children that are composed of either similar or dissimilar cross-case letters), and to have a large enough number of items per condition, each target word was presented several times (see Bowers et al., 1998, for the same procedure). It is important to note here that Perea et al. (2014) found the same pattern of masked identity priming effects regardless of whether there was a single presentation of the target word or several presentations of the target word. As in Jacobs et al. (1995) and Perea et al. (2014) experiments, a 16-ms pattern mask was inserted between prime and target to avoid perceptual continuity.

Method

Participants

The participants were 19 third graders (mean age = 7 years 9 months, range = 7.4–8.3 years) and 19 fifth graders (mean age = 9 years 10 months, range = 9.5–10.3 years) from a public school in Valencia, Spain, and 19 first-year students from the University of Valencia (mean age = 19 years 3 months, range = 18–20 years). All participants were native speakers of Spanish and had normal (or corrected-to-normal) vision. None of them had any sensory, neurological, or learning disabilities. All children were reported to have normal scores on standardized reading/cognitive tests.

Materials

We selected 32 target words in Spanish, all of them having four letters. For 16 of these words, most (three or four) of the constituent letters were visually dissimilar across case (DIS words; e.g., arte–ARTE). The median word frequencies in the Spanish B-Pal database (Davis & Perea, 2005) and children LEXIN database (Corral, Ferrero, & Goikoetxea, 2009) were 21 and 21 per million, respectively (mean Coltheart’s $N = 7.8$). For the remaining 16 words, most (three or four) of the constituent letters were visually similar across case (SIM words; e.g., vivo–VIVO). The median word frequencies in the B-Pal database and LEXIN database were 32 and 21 per million, respectively (mean Coltheart’s $N = 5.1$).

These similar/dissimilar cross-case letters were chosen on the basis of Boles and Clifford's (1989) ratings (dissimilar letters: a/A, b/B, d/D, e/E, l/L, g/G, h/H, and r/R; similar letters: c/C, i/I, k/K, m/M, n/N, s/S, t/T, u/U, v/V, and w/W). We also created two sets of 16 pronounceable pseudowords with the same characteristics as the words (e.g., DIS pseudowords such as ERED, DIM pseudowords such as BITU). The complete list of words and pseudowords is presented in the Appendix. The target was presented in uppercase and preceded by a prime stimulus that was (a) the same as the target and in the same case (e.g., ARTE–ARTE, VIVO–VIVO), (b) the same as the target except that it was in lowercase (e.g., arte–ARTE, vivo–VIVO), (c) an unrelated word (half in lowercase and half in uppercase), or (d) an unrelated pseudoword (half in lowercase and half in uppercase). Each target word was presented in the identity and unrelated conditions four times, thereby leading to 16 trials per condition.

Procedure

The session took place in groups of 3 or 4 individuals in a quiet room using DMDX (Forster & Forster, 2003). The sequence of a given trial was the following:

1. A forward pattern mask (####) was presented for 500 ms.
2. A prime stimulus was presented for 33.3 ms (two refresh cycles in the 60-Hz CRT monitor).
3. A pattern mask (####) was presented for 16.6 ms.
4. The target stimulus was presented until the participant responded or 2 s had passed.

Stimuli were presented in the same spatial location using the Courier New font. Participants were instructed to press a "sí" (yes) button if the letter string formed a Spanish word and to refrain from responding if the letter string did not form a word, and they were told to be "as fast as possible while avoiding making many errors." There were 16 practice trials before the experimental phase (256 trials). There was a self-paced break after 120 trials. The session lasted approximately 11 to 15 min.

Results

Error responses (3.2% of all responses) and response times (RTs) shorter than 250 ms (<0.01% of all responses) were excluded from the RT analyses. In addition, correct RTs beyond 3 standard deviations from the participant's RT mean were excluded as well. Given that, as in previous research, word and pseudoword unrelated primes behaved similarly (Perea et al., 2014), the two unrelated conditions were merged in the analyses. Thus, we conducted analyses of variance (ANOVAs) on the mean RTs and percentage of error per condition with prime–target relatedness (matched-case identity, mismatched-case identity, or unrelated), Type of word (cross-case similar or cross-case dissimilar), and age (third graders, fifth graders, or college students) as factors. The mean RTs and percentage error in each condition are displayed in Table 1. The ANOVAs were conducted over participants (F_1) and items (F_2).

Unsurprisingly, the ANOVA on the latency data revealed an effect of age, $F_1(2,54) = 26.86$, $MSE = 96571$, $\eta^2 = .50$, $p < .001$; $F_2(2,30) = 9977.7$, $MSE = 12450$, $\eta^2 = .98$, $p < .001$. Mean RTs for third graders, fifth graders, and university students were 832, 658, and 532 ms, respectively. But the critical finding was the significant three-way interaction among prime–target relatedness, type of word, and age, $F_1(2,54) = 3.96$, $MSE = 1237$, $\eta^2 = .13$, $p = .005$; $F_2(4,60) = 3.25$, $MSE = 1275$, $\eta^2 = .18$, $p = .018$. To examine this interaction in detail, we examined the effects of prime–target relatedness and type of word along the three groups of participants.

University students

We found a relatedness effect, $F_1(2,36) = 49.37$, $MSE = 520$, $\eta^2 = .73$, $p < .001$; $F_2(2,30) = 63.01$, $MSE = 353$, $\eta^2 = .81$, $p < .001$. Response times were shorter in the matched-case and mismatched-case identity conditions (516 and 518 ms, respectively) than in the unrelated condition (562 ms) (all $ps < .001$); there were virtually no differences in the matched-case and mismatched-case identity priming conditions (2 ms) (both $Fs < 1$). Neither the effect of case nor the interaction between

Table 1
Mean response times (in ms) and percentages of errors for word and pseudoword targets.

	Words				Pseudowords	
	SIM letters		DIS letters		SIM letters	DIS letters
	RT	ER	RT	ER	ER	ER
College students						
Matched-case repetition	520 (14.7)	0.0 (0.0)	516 (15.0)	0.3 (0.3)	4.9 (1.0)	1.0 (0.7)
Mismatched-case repetition	513 (13.8)	0.3 (0.3)	519 (16.0)	0.0 (0.0)	2.0 (0.7)	1.6 (0.8)
Unrelated	562 (14.4)	0.2 (0.2)	562 (15.3)	0.2 (0.2)	3.3 (0.8)	1.6 (0.4)
Mismatched minus matched	−7	0.3	3	−0.3	−2.9	0.6
Fifth-grade children						
Matched-case repetition	620 (31.5)	2.6 (1.2)	648 (34.9)	3.6 (1.3)	8.6 (1.8)	4.3 (1.4)
Mismatched-case repetition	625 (30.3)	2.0 (0.8)	634 (32.9)	3.9 (1.9)	11.5 (1.5)	5.6 (1.4)
Unrelated prime	710 (37.5)	2.8 (1.0)	711 (36.8)	3.0 (0.8)	7.2 (1.5)	3.5 (0.9)
Mismatched minus matched	5	−0.6	14	0.3	2.9	1.3
Third-grade children						
Matched-case repetition	827 (33.7)	8.2 (1.7)	798 (38.0)	6.3 (1.5)	8.9 (2.3)	3.0 (0.7)
Mismatched-case repetition	811 (37.7)	6.3 (1.4)	850 (40.8)	5.3 (1.6)	8.6 (1.9)	4.6 (1.6)
Unrelated prime	858 (34.5)	7.9 (1.7)	850 (35.4)	6.3 (1.6)	8.2 (1.7)	3.8 (1.2)
Mismatched minus matched	−16	−1.9	52	−1.0	−0.3	1.6

Note. Standard errors are in parentheses. SIM letters, stimuli composed mostly of cross-case similar letters; DIS letters, stimuli composed mostly of cross-case dissimilar letters; RT, response time (ms); ER, percentage of errors.

relatedness and type of word approached significance (all *F*s < 1). Therefore, these data replicated previous masked priming experiments with adult readers (Bowers et al., 1998; Jacobs et al., 1995; Perea et al., 2014).

Fifth-grade children

The relatedness effect was significant, $F_1(2,36) = 51.39$, $MSE = 1535$, $\eta^2 = .75$, $p < .001$; $F_2(2,30) = 14.16$, $MSE = 1658$, $\eta^2 = .49$, $p < .001$. This reflected shorter latencies in the matched-case and mismatched-case identity conditions (630 and 634 ms, respectively) than in the unrelated condition (711 ms) (all *p*s < .001); again, there were virtually no differences between the matched-case and mismatched-case identity priming conditions (4 ms) (both *F*s < 1). The effect of type of word approached significance in the analysis by participants, $F_1(1,18) = 3.70$, $MSE = 1301$, $\eta^2 = .17$, $p = .071$; $F_2 < 1$. Finally, the interaction between the two factors was not significant (both *p*s > .15). In sum, the pattern of data from fifth graders is remarkably similar to that from adult readers.

Third-grade children

The relatedness effect was significant, $F_1(2,36) = 6.40$, $MSE = 2542$, $\eta^2 = .26$, $p = .004$; $F_2(2,30) = 13.71$, $MSE = 1463$, $\eta^2 = .48$, $p < .001$. But more important, there was a significant interaction between relatedness and type of word, $F_1(2,36) = 4.62$, $MSE = 2477$, $\eta^2 = .21$, $p = .016$; $F_2(2,30) = 3.43$, $MSE = 1512$, $\eta^2 = .19$, $p = .046$. For SIM words, the relatedness effect, $F_1(2,36) = 4.63$, $MSE = 2340$, $\eta^2 = .21$, $p = .016$; $F_2(2,30) = 6.29$, $MSE = 1780$, $\eta^2 = .30$, $p = .005$, revealed an advantage of the matched-case and mismatched-case identity priming conditions (827 and 811 ms, respectively) over the unrelated condition (858 ms), $t_1(18) = 1.73$, $\eta^2 = .14$, $p = .10$; $t_2(15) = 3.77$, $\eta^2 = .49$, $p = .002$, and $t_1(18) = 3.28$, $\eta^2 = .37$, $p = .004$; $t_2(15) = 2.63$, $\eta^2 = .32$, $p = .018$, respectively. Note that, as occurred with fifth graders and young adults, the difference between the matched-case and mismatched-case identity priming conditions did not approach significance (both *p*s > .50).[1] The pattern of data for DIS words

[1] For SIM words, 74% of third graders (14 of 19) showed faster RTs in the matched-case identity condition than in the unrelated condition, so that the lack of a significant effect in the by-participants analyses was probably due to within-participant variability in RTs. We should note here that the analysis combining the two identity conditions (e.g., vivo–VIVO and VIVO–VIVO) versus the unrelated condition revealed a significant masked identity priming effect (both *p*s < .015).

was substantially different; the relatedness effect, $F_1(2,36) = 6.34$, $MSE = 2678$, $\eta^2 = .26$, $p = .004$; $F_2(2,30) = 11.75$, $MSE = 1196$, $\eta^2 = .44$, $p < .001$, reflected an advantage of the matched-case identity priming condition not only over the unrelated priming condition (798 vs. 850 ms, respectively), $t_1(18) = 3.49$, $\eta^2 = .40$, $p = .003$; $t_2(15) = 3.14$, $p = .007$, but also over the mismatched-case identity condition (850 ms), $t_1(18) = 2.83$, $\eta^2 = .31$, $p = .011$; $t_2(15) = 3.33$, $\eta^2 = .42$, $p = .005$. Indeed, there were virtually no differences between the mismatched-case identity priming condition and the unrelated priming condition (both *t*s < 1). That is, the prime arte did not facilitate the processing of the DIS word ARTE more than an unrelated prime.

The ANOVA on the error rates only revealed an effect of age, $F_1(2,54) = 14.99$, $MSE = 81.4$, $\eta^2 = .36$, $p < .001$; $F_2(2,30) = 28.28$, $MSE = 36.3$, $\eta^2 = .65$, $p < .001$. This reflected a negligible error rate for university students (0.2%), which was 3.0% for fifth graders and increased to 6.7% for third graders (all *p*s < .023). None of the other effects was significant (all *p*s > .13).

Pseudoword targets

The ANOVA on the error rates revealed an effect of age, $F_1(2,54) = 7.48$, $MSE = 14.2$, $\eta^2 = 22$, $p = .001$; $F_2(2,30) = 12.17$, $MSE = 44.0$, $\eta^2 = .45$, $p < .001$. University students committed fewer pseudoword errors (2.4%) than the young readers (6.2 and 6.8% for fifth and third graders, respectively) (all *p*s < .004), whereas there were no differences between the two groups of young readers (both *p*s > .40). In addition, participants committed more errors to SIM pseudowords than to DIS pseudowords (7.0 vs. 3.2%), $F_1(1,54) = 38.34$, $MSE = 32.2$, $\eta^2 = .42$, $p < .001$; $F_2(1,15) = 7.45$, $MSE = 138.7$, $\eta^2 = .33$, $p = .016$. None of the other effects approached significance (all *p*s > .10).

Discussion

The purpose of the current experiment was to examine the developmental trajectory of rapid access to abstract lexical representations by comparing the magnitude of masked priming effects of cross-case visually similar (SIM) and dissimilar (DIS) words in third graders, fifth graders, and young adults. For adults, we found similar word identification times for matched-case and mismatched-identity pairs in DIS words (arte–###–ARTE vs. ARTE–###–ARTE) and SIM words (vivo–###–VIVO vs. VIVO–###–VIVO). Furthermore, the masked repetition priming effect relative to the unrelated condition was similar for DIS words and SIM words. Fifth graders showed a pattern of data remarkably similar to the adult readers for both SIM and DIS words. Therefore, masked priming effects with adults and fifth graders reflect the rapid activation of abstract representations. In contrast, this fast access to the abstract representations process does not seem to be fully completed by third graders, as revealed by the pattern of data with DIS words (matched-case identity < mismatched-case identity = unrelated).[2] Note that for SIM words the pattern of data of third graders resembled that of adult readers and fifth graders (matched-case identity = mismatched-case identity < unrelated); this pattern of results could be explained in terms of visual similarity across primes and targets.

To examine in further detail the advantage of matched-case identity over mismatched-case identity pairs for DIS words in third graders, we conducted RT distributional analyses. Results revealed that the advantage of ARTE–ARTE over arte–ARTE was 19, 7, 34, 64, and 122 ms in the .1, .3, .5, .7, and .9 quantiles, respectively. This pattern suggests that this difference does not have its locus at an (early) encoding stage; rather, it has it at the lexical evidence accumulation stage.[3] That is, there was rapid access to the abstract representations, as deduced from the .1 and .3 quantiles, but the quality of the

[2] We computed the Bayes factors (Rouder, Speckman, Sun, Morey, & Iverson, 2009) for this comparison. The likelihoods of the alternative over the null hypothesis were 15.2 in the analysis by participants and 7.1 in the analysis by items. This implies a reasonable degree of support for the alternative hypothesis.

[3] In an evidence accumulation account of the lexical decision task (Gomez, Perea, & Ratcliff, 2013; Ratcliff, Gomez, & McKoon, 2004), it is assumed that RTs are a sum of the evidence accumulation process, the encoding processes, and the response execution. If encoding effects occur across conditions, there is a shift in the latency distribution (i.e., the effects are of similar size across all of the quantiles). In contrast, if the effects are in the quality of the evidence being accumulated (e.g., the lexical representation of a string of letters), the effects are smaller in the first quantiles than in the later quantiles.

orthographic representations in arte–ARTE pairs was not as strong, as deduced from the RT data in the higher quantiles. Note that masked identity priming with adult readers only reveals an effect in the encoding stage (Gomez, Perea, & Ratcliff, 2013).

The current experiment represents a modest step to map the developmental trajectory of a process that is critical for fluent reading—the consolidation of an abstract representation shared by different versions of the same letter. It is widely accepted that access to abstract representations is very fast for adults; here, we have provided evidence that by fifth grade children have already developed highly efficient access to those representations. Interestingly, this process does not seem to be fully operative by third grade. This is consistent with Thompson's (2009) claim concerning the long route to efficiently use abstract representations in children. Further experimentation is necessary to examine in detail the time course of the processing of visual versus abstract representations in developing readers (e.g., registering participants' ERP (event-related potential) waves, monitoring participants' eye movements during reading, examining RT distributions) and, as suggested by a reviewer, how this pattern could be modulated by the level of reading ability across developing readers (with the expectation that the difference between the SIM and DIS effects would be greater for the less advanced readers). Another aspect that requires further research is to explicitly test the idea that visually similar letters may provide the context to create abstract representations, as suggested by Polk et al. (2009). Finally, the current findings also provide a cautionary note regarding the interpretation of masked priming effects with younger readers. Masked priming effects in young readers (in particular third graders or younger) might not rely on the same mechanism as in adults or older children; instead, they might just be a consequence of the visual similarity between primes and targets.

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Appendix List. of stimuli

DIS words; DEDO, DEJA, CAER, CERA, RATA, ALTA, BATA, BAÚL, TELE, LEÑA, ALGA, ANDA, PEGA, AMAR, ARTE, and EDAD.

SIM words: UNIR, CIEN, VINO, SEIS, VIVA, CINE, CASI, MIMO, SUMA, VIVO, CITA, BICI, KIWI, MISA, CUNA, and IMÁN.

DIS pseudowords: EDGA, REVA, DAKE, WEDE, MEER, DERU, EMAB, EGTE, BAME, AMEG, ETDA, CEHE, BEÑE, GIAL, ERED, and EBTA.

SIM pseudowords: VUME, NUVO, ITÉN, BITU, TISE, CISE, MISE, NAIS, CEVI, CONU, VUCA, MUWI, CUVE, ETUC, IVIR, and CUEK.

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