Psychonomic Bulletin & Review (2019) 26:347–352
https://doi.org/10.3758/s13423-018-1503-0

BRIEF REPORT

# Shared or separated representations for letters with diacritics?

**Fabienne Chetail**[1] · **Emeline Boursain**[1]

**Abstract**

Understanding the front end of visual word recognition requires us to identify the processes by which letters are identified. Since most of the work on letter recognition has been conducted in English, letter perception modeling has been limited to the 26 letters of the Latin alphabet. However, many writing systems include letters with diacritic marks. In the present study, we examined whether diacritic letters are a mere variant of their base letter, and thus share the same abstract representation, or whether they function as separate elements from any other letters, and thus have separate representations. In Experiments 1A and 1B, participants performed an alphabetical decision task combined with masked priming. Target letters were preceded by the same letter (e.g., *a–A*), by a diacritic letter (e.g., *â–A*), or by an unrelated letter (e.g., *z–A*). The results showed that the primes sharing nominal identity (e.g., *a*) facilitated target processing as compared to unrelated primes (e.g., *z*), but that primes that included a diacritic mark (e.g., *â*) did not, with reaction times being similar to those in the unrelated priming condition. In Experiment 2 we replicated these results in a lexical decision task. Overall, this demonstrates that as long as diacritics are used in scripts to distinguish between lexical entries, the diacritic letters are not mere variants of their base letters but constitute unitary elements of the script in their own right, with diacritics contributing to the overall visual shape of a letter.

**Keywords** Visual word recognition · Letter perception · Diacritics · Accent

For many decades, researchers have endeavored to understand the processes underpinning written word recognition. The challenge has been to explain how readers succeed in extracting orthographic, phonological, and semantic information from printed marks in a quarter of a second. Despite the intuitive feeling that written words are recognized holistically, it is well admitted that word recognition rests upon the activation of individual letter representations, which in turn activate word representations (see Rayner, Schotter, Masson, Potter, & Treiman, 2016). Understanding the front end of visual word recognition therefore necessitates identifying the processes by which letters are identified.

Current theories endorse Selfridge (1959) feature-based proposal to account for letter perception. The main idea is that the form and position of letter features are gradually encoded via an increasingly complex network of neurons (see Grainger, Rey, & Dufau, 2008). When a written word is presented, the iconic trace formed from the sensory information excites neurons coding for the different simple features of letters (e.g., | and – for E). In turn, these neurons send excitation to other groups of neurons coding for increasingly complex configurations (combinations of features). This hierarchy of levels eventually leads to the activation of neurons coding for the identity of letters independently from their size, shape, or font (e.g., *a*, a, A, A). Direct support for this proposal has come from letter and word priming experiments (e.g., Bowers, Vigliocco, & Haan, 1998; Ziegler, Ferrand, Jacobs, Rey, & Grainger, 2000). In the alphabetical decision task (speeded letter–nonletter categorization), letter recognition is facilitated when the target is primed briefly by the same letter presented in a different case (e.g., *a* priming *A*) as compared to a control priming condition (e.g., *x* priming *A*). The facilitation is present both when the prime is visually similar to the target (e.g., *c–C*) and when it is not (e.g., *a–A*), although priming is usually stronger in the latter case (e.g., Ziegler et al., 2000). In the lexical decision task (speeded word–nonword categorization), word recognition is also facilitated by a cross-case prime that consists of letters either similar or dissimilar from the target

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✉ Fabienne Chetail
fchetail@ulb.ac.be

[1] Laboratoire Cognition Langage, & Développement (LCLD), Centre de Recherche Cognition et Neurosciences (CRCN), Université Libre de Bruxelles (ULB), Av. F. Roosevelt, 50/CP 191, 1050 Brussels, Belgium

(e.g., *cook–COOK* and *able–ABLE*, respectively; Bowers et al., 1998).

Since most of the work on letter recognition has been conducted in English, letter perception modeling has been limited to the 26 letters of the Latin alphabet. However, many writing systems using the Latin script include letters with diacritic marks that are variants of the 26 basic letters. This is the case in languages such as French (e.g., *é*, *â*), Spanish (e.g., *ó*, *ñ*), Turkish (e.g., *ğ*, *ş*), or Vietnamese (e.g., *ữ*, *ạ*). Diacritics are typically defined as features added to a regular letter to indicate a phonemic value, to provide suprasegmental information (stress, tone), or to distinguish between homophonic words (Protopapas & Gerakaki, 2009).[1] Although there is no reason to think that the core processes of letter perception are different across alphabetical scripts, the processing of regular letters and their variants within a script could differ. The present study addresses this issue and provides empirical evidence to answer this question: Are diacritic letters a mere variant of their base letter (i.e., activating the same abstract representation), or do diacritic letters function as elements separate from any other letter (i.e., with separate representations from their base letters)?

Arguments can be put forward for each alternative. Letters are used to transcribe the distinct phonemes of a language (e.g., *p* for /p/). Hence, as long as diacritic letters are used to modify the phonetic value of letters, and thus to code for specific phonemes (e.g., *é* vs. *e* in French for /e/ vs. / /), they may be processed as distinct elements. Even if no different phonemic or phonetic value is assigned to a diacritic letter, the mere fact that it can distinguish between two lexical entries (e.g., *tache* vs. *tâche*, both pronounced /tɑ / and meaning *stain* and *task*, respectively), as other base letters do (e.g., *lait* vs. *laid* meaning *milk* vs. *ugly*), may give the full status of a letter to diacritic letters. Furthermore, in some languages such as Turkish, children learn the base letters and their diacritic variants separately, each form having a different name. Also, given that diacritic letters are as frequent as their base letters, Turkish readers do not have a strong motivation to see them as exceptional variants of their nondiacritic counterparts (Ayçiçeği & Harris, 2002).

On the other hand, the huge visual overlap between a diacritic letter and its base letter—sometimes added to a substantial phonological overlap—may lead readers to process the two written stimuli as variants of the same letter. In that case, diacritic and nondiacritic letters would share a single abstract letter representation. In addition, the fact that diacritic marks are recurrent within an alphabet (e.g., *î*, *ô*, *â*) may lead people to analyze them separately from their base letter. When processed, a diacritic letter would thus be decomposed as the base letter plus the mark (Ayçiçeği & Harris, 2002). Finally, in some scripts (e.g., Spanish, Greek), diacritics do not contribute to establishing the orthographic or phonological form of words, but instead make stress patterns explicit. The information conveyed by diacritics would therefore be computed separately from letter identity and would be used for lexical access only (Protopatas & Gerakaki, 2009). In that case, there is no reason that visual inputs such as *a* and *á* in Spanish words (e.g., *pájaro* or *bailar*) would activate separate letter representations.

To examine how diacritics are processed, most studies so far have used word naming tasks in scripts with diacritics to mark stress (e.g., Cubelli & Beschin, 2005; Gutiérrez-Palma & Palma-Reyes, 2008; Protopapas & Gerakaki, 2009). However, these studies do not make it possible to address the issue of shared or separated representations of diacritic letters during letter perception, since in this case the diacritics are not relevant for letter perception. This question can be addressed only in orthographies for which diacritic letters have a proper phonemic value and/or distinguish between homophonic words (e.g., French, Turkish, German). To our knowledge, only one study has been conducted from this perspective (Ayçiçeği & Harris, 2002, in Turkish). In that study, words were displayed with rapid serial visual presentation (RSVP). Typically, when two orthographically similar words among four are presented, the repeated letters in the second word are not detected, which leads to a deficit in reporting this word. Accordingly, in Ayçiçeği & Harris's study, word report was lower when the two targets shared all letters but one (neighbor condition; e.g., *cami*–***bel***–*rüya*–***bol***, with the target words in bold) than in an unrepeated condition (e.g., *cami*–***sur***–*rüya*–***bol***). More critically, word report was also lower when the two words differed by only a diacritic mark (e.g., *cami*–***böl***–*rüya*–***bol***), as compared to both the unrepeated and neighbor conditions, and was similar to word report in the repeated condition (e.g., *cami*–***bol***–*rüya*–***bol***). According to the authors, this demonstrated that pairs of letters differing by a simple diacritic mark are not processed as two different letters, and thus activate the same letter representation.

In the present study, we tested the alternative hypotheses of shared or separate representations for diacritic letters, with tasks deemed to be more appropriate to examining letter perception (e.g., Bowers et al., 1998; Ziegler et al., 2000). In Experiments 1A and 1B, participants performed an alphabetical decision task combined with masked priming. The target letters were preceded by the same letter (e.g., *a–A*), by a diacritic letter (e.g., *â–A*), or by an unrelated letter (e.g., *z–A*). If the presentation of *a* and *â* activates the same letter representation, we expected the recognition times for *â–A* to be close to those for *a–A*, and faster than those for *z–A*. If the presentation of *a* and *â* leads to the activation of two distinct letter representations, the recognition times for *â–A* should be

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[1] In consonant alphabets (e.g., Arabic, Hebrew), diacritics are used to represent vowels and are usually omitted. These diacritics therefore do not produce letter variants—a situation examined in the present study—but enrich the consonantal form of written words.

longer than those for *a–A* and close to those for *z–A*. To anticipate, Experiment 1B was conducted to replicate Experiment 1A, since the results were different from those of Ayçiçeği and Harris (2002). In Experiment 2, we generalized the priming design to word recognition.

# Experiment 1

## Method

**Participants** Groups of 50 and 38 students participated to Experiments 1A and 1B, respectively, for course credits. All were native speakers of French with normal or corrected-to-normal vision and without any language disorder.

**Materials** In French, diacritic marks are almost exclusively present on vowel letters. We therefore chose eight frequent combinations of accentuations among vowel letters (*a*/*à*, *a*/*â*, *e*/*é*, *e*/*è*, *i*/*î*, *o*/*ô*, *u*/*ù*, *u*/*û*). The five letters without accents were the targets (e.g., *A*), for which three primes were selected: a repeated (*a*), a diacritic (*à*), and an unrelated (*z*) prime. This led to eight different triplets (Table 1). Each combination of target–prime was repeated five times, leading to 120 trials (written in Courier New font) for positive responses. For negative responses we used the same triplets of primes, but the targets were pseudoletters coming from BACS1. They had the same visual complexity as letters (see Vidal, Content, & Chetail, 2017). The same items were used in Experiments 1A and 1B.

**Procedure** In both experiments, participants performed an alphabetical decision task programmed with PsychoPy (Peirce, 2007). Each trial began by a fixation cross, presented for 500 ms at the center of the screen (1,280 × 1,024 resolution, at a distance of 60 cm), and followed by a mask for 500 ms (#). The lowercase prime was then presented for 50 ms and immediately followed by the uppercase target, which remained on the screen until the participant responded. The font size was 40-point, and the stimuli were presented in white against a black background. Participants were instructed to decide as rapidly and accurately as possible whether or not the targets were letters by pressing buttons on a keyboard. Visual feedback was provided when participants failed to respond. They performed eight practice trials before receiving the 240 trials in a variable random order.

## Results and discussion

Statistical analyses were run with R packages (R Core Team, 2015). The mean correct reaction times and mean error rates, averaged over participants, are presented in Table 2. We excluded trials eliciting very long (>2,000 ms) or very short (<200 ms) reaction times (0.04% and 0.63% of the data in Exps. 1A and 1B, respectively). Overall, the average reaction times were 491 ms ($SD$ = 113) and 516 ms ($SD$ = 149) for positive responses, and 528 ms ($SD$ = 119) and 555 ms ($SD$ = 148) for negative responses. The data were then submitted to separate analyses of variance on the participant and item means for positive responses, with prime type as the main factor. We had two planned comparisons (repeated vs. diacritic/unrelated, and diacritic vs. unrelated).

**Experiment 1A** In reaction times, we observed a main effect of priming, $F_1(2, 98) = 19.53, p < .001$, $F_2(2, 14) = 40.57, p < .001$. Repeated primes led to shorter reactions times than did the two other conditions, $F_1(1, 49) = 37.69, p < .001$, $F_2(1, 7) = 108.6, p < .001$, whereas there was no significant difference between the

**Table 1** Combinations of primes and targets in Experiments 1A and 1B for positive and negative responses

| Type of response | | | | | | | |
|---|---|---|---|---|---|---|---|
| Yes | | | | No | | | |
| Type of prime | | | Targets | Type of prime | | | Targets |
| Repeated | Diacritic | Unrelated | | Repeated | Diacritic | Unrelated | |
| a | à | z | A | a | à | z |  |
| a | â | w | A | a | â | w |  |
| e | è | r | E | e | è | r |  |
| e | é | n | E | e | é | n |  |
| i | î | c | I | i | î | c |  |
| o | ô | v | O | o | ô | v |  |
| u | ù | s | U | u | ù | s |  |
| u | û | x | U | u | û | x |  |

**Table 2** Mean reaction times (RTs, in milliseconds) and percentage of errors on target letters in Experiments 1A and 1B (standard deviations are in parentheses)

| Prime Type | Experiment 1A | | Experiment 1B | |
|---|---|---|---|---|
| | RTs | Error rates | RTs | Error rates |
| Repeated (e.g., a–A) | 479 (34) | 2.8 (11.8) | 502 (46) | 3.3 (10.4) |
| Diacritic (e.g., à–A) | 497 (40) | 3.5 (11.8) | 520 (72) | 4.5 (12.0) |
| Unrelated (e.g., z–A) | 496 (43) | 2.5 (9.8) | 525 (74) | 3.3 (11.6) |

diacritic and the unrelated priming conditions, $F_1 < 1$, $F_2(1, 7) = 1.19$, $p = .31$. The main effect of prime type was not significant in error rates, $F_1(2, 98) = 1.23$, $p = .30$, $F_2(2, 14) = 4.42$, $p = .03$.

**Experiment 1B** In reaction times, we found a main effect of priming, $F_1(2, 74) = 17.13$, $p < .001$, $F_2(2, 14) = 17.49$, $p < .001$. Repeated primes again led to shorter reactions times than did the two other conditions, $F_1(1, 37) = 32.17$, $p < .001$, $F_2(1, 7) = 30.08$, $p < .001$, whereas there was no significant difference between the diacritic and unrelated priming conditions, $F(1, 37) = 1.17$, $p = .29$, $F_2(1, 7) = 1.12$, $p = .33$. The main effect of prime type was not significant in error rates, $F_1(2, 74) = 2.66$, $p = .08$, $F_2(2, 14) = 1.35$, $p = .29$.

The results were clear cut and identical in both experiments: Reaction times for diacritic primes were similar to those for unrelated primes, and strongly differed from those for repeated primes. This suggests that the prime *a* preactivates an abstract representation shared by the letter *A*, and thus facilitates target processing as compared to a control prime condition, whereas the prime *à* does not. In other words, a diacritic letter and its base letter do not activate the same letter representation.

Processing letters within words involves processes that do not occur during single-letter identification, such as crowding (e.g., Grainger, Tydgat, & Isselé, 2010). It was therefore necessary to test whether the results reported in Experiment 1 would hold true when the manipulation was made within words rather than in isolated letters. To do so, the participants in Experiment 2 performed a lexical decision task combined with masked priming. The target words (e.g., *TAPER*) were preceded by a repeated (e.g., *taper*), a diacritic (e.g., *tâper*), an orthographic neighbor (e.g., *tuper*), or an unrelated (e.g., *brume*) word prime. We expected the repeated prime to facilitate word recognition relative to the unrelated prime (e.g., Forster & Davis, 1984). We also expected shorter reaction times with the diacritic and orthographic neighbor primes than with the unrelated prime, because both the former primes are pseudowords that share most of their letters with the target (e.g., Segui & Grainger, 1990). Furthermore, if the results of Experiment 1 were to replicate, these two conditions should lead to longer reaction times than repeated primes would, whereas no significant difference should be found between the two conditions.

## Experiment 2

### Method

**Participants** A group of 42 new students participated in the experiment. They had the same characteristics as those in Experiment 1.

**Materials** A total of 104 five-letter words were selected from Lexique 3.80 (New, Pallier, Brysbaert, & Ferrand, 2004). Each item included at least one letter in the second, third, or fourth position that could legally occur with a diacritic mark (e.g., *a* in *taper*). Four primes were devised for each target: the same word as the target (repeated prime: e.g., *taper* for *TAPER*), the same word with an accent on a central vowel letter (diacritic prime: e.g., *tâper*), a pseudoword sharing all but one letter with the target (pseudoword prime: e.g., *tuper*), and an unrelated word (unrelated prime: e.g., *brume*). The modified letter in the diacritic and pseudoword primes was at the same position. To meet the task requirements, 104 legal pseudoword targets were devised. They were matched with the words on length, bigram frequency, and ODL20, and the same four priming conditions were used.

**Procedure** The procedure was similar to that in Experiment 1, except that the participants had to perform a lexical decision task. After a mask presented for 500 ms (#####), the prime was displayed for 50 ms and immediately followed by the target. Participants were asked to decide as rapidly and accurately as possible whether or not the target was a French word.

### Results and discussion

The mean correct reaction times and mean error rates, averaged over participants, are presented in Table 3. We excluded trials eliciting very long (> 2,000 ms) or very short (< 300 ms) reaction times (2.59% of the data). Items or participants eliciting 33% or more errors were also excluded (seven items,

**Table 3** Mean reaction times (RTs, in milliseconds) and percentage of errors on target letters in Experiment 2 (standard deviations are in parentheses)

| Prime Type | RTs | Error Rates |
|---|---|---|
| Repeated (e.g., *taper–TAPER*) | 724 (60) | 6.2 (14.9) |
| Diacritic (e.g., *tâper–TAPER*) | 774 (82) | 10.2 (14.5) |
| Pseudoword (e.g., *tuper–TAPER*) | 781 (83) | 10.1 (13.6) |
| Unrelated (e.g., *brume–TAPER*) | 802 (83) | 7.9 (14.9) |

one participant). Overall, the average reaction times for positive and negative responses were 766 ms (*SD* = 239) and 902 ms (*SD* = 280), respectively. The data were submitted to separate analyses of variance on the participant and item means for positive responses, with prime type as the main factor. We had three planned comparisons: unrelated versus the other three conditions, repeated versus diacritic/unrelated, and diacritic versus unrelated.

In reaction times, we found a main effect of priming, $F_1(3, 120) = 21.53$, $p < .001$, $F_2(3, 288) = 11.72$, $p < .001$. The unrelated prime condition led to longer reactions times than did the other conditions, $F_1(1, 40) = 27.08$, $p < .001$, $F_2(1, 96) = 17.79$, $p < .001$. Critically, the repeated prime condition led to shorter reactions times than did the diacritic and pseudoword conditions, $F_1(1, 40) = 35.09$, $p < .001$, $F_2(1, 96) = 18.81$, $p < .001$, whereas there was no significant difference between the diacritic and unrelated priming conditions, $F < 1$.

In error rates, the effect of priming was marginally significant in the item analyses, $F_1(3, 120) = 3.74$, $p = .01$, $F_2(3, 288) = 2.32$, $p = .08$. The unrelated prime condition did not differ significantly from the other conditions, $F_1 < 1$, $F_2(1, 96) = 2.70$, $p = .10$. Critically, the repeated prime condition led to fewer errors than the diacritic and pseudoword conditions, $F_1(1, 40) = 11.51$ $p = .002$, $F_2(1, 96) = 3.89$, $p = .05$, whereas there was no significant difference between the diacritic and unrelated priming conditions, $F < 1$.

These results mirror those of Experiments 1A and 2A and clearly suggest that the presentation of primes such as *a* and *â* does not preactivate the same letter representation. Only the abstract letter identity preactivated by *a* facilitates processing of the visual input *A*.[2]

## General discussion

In three experiments, we showed that priming an uppercase target (e.g., *A* or *TAPER*) with a lowercase prime sharing its nominal identity (e.g., *a*, *taper*, respectively) facilitates its processing as compared to an unrelated prime (e.g., *z*, *tuper*) (e.g., Bowers et al., 1998; Ziegler et al., 2000). However, when the primes included a diacritic mark (e.g., *â*, *tâper*), they did not facilitate processing, with reaction times being similar to those in the unrelated priming condition.

In the hierarchically organized layers of feature and feature configuration detectors, written stimuli such as *a* and *â* excite identical detectors at the first level, given their high degree of visual similarity (e.g., Grainger et al., 2008). Our results demonstrate, however, that the whole process of letter perception eventually leads to the activation of distinct abstract representations of letter identity. Hence, as long as diacritics are used in scripts to distinguish between lexical entries, the diacritic letters are not mere variants of their base letters. On the contrary, they constitute unitary elements of the script in their own right, with diacritics contributing to the overall visual shape of the letters they are combined with. The high visual similarity between a diacritic letter and its base letter could have led to the opposite hypothesis (e.g., Ayçiçeği & Harris, 2002), but it is worth noting that some letters among the 26 of the Latin alphabet also have a high degree of visual overlap (e.g., the difference between *e* and *c* is a small horizontal stroke, just as the difference between *e* and *é* is a small slanted stroke). Yet nobody would question the existence of distinct abstract identity representations for visual inputs such as *e* and *c*.

Our results and conclusions differ from those reported by Ayçiçeği and Harris (2002). It does not seem that differences between French and Turkish could account for this discrepancy. As was reported by those authors, children learn the base letters and their diacritic variants separately in Turkish, with each form having a different name, and the diacritic letters are as frequent as their base letters. The other main difference between the two studies was the nature of the tasks used to examine letter perception—namely, lexical and alphabetical decision tasks combined with masked priming, here, versus RSVP presentation combined with a repetition blindness situation, for Ayçiçeği and Harris. The former tasks are largely used to investigate print processing and are assumed to be relevant to examining letter perception and orthographic word form processing (see New & Grainger, 2011). On the contrary, the latter task includes a memory component, and its results could have been weakened by the necessity of a verbal report. Furthermore, all Ayçiçeği and Harris's stimuli were displayed in lowercase, thus making it not possible to investigate the access to abstract letter representations, independent from case and shape.

To conclude, we have demonstrated that base letters and their diacritic counterparts activate separated letter representations in scripts such as French. At a theoretical level, there is therefore no reason to assume specific processing mechanisms for diacritic letter perception. At a methodological level, this means that some of the great efforts made in recent years to establish visual word recognition modeling (e.g., easyNet; Adelman, Davis, & Dubian, n.d.) remain limited to scripts without diacritics, such as English. Yet, cross-linguistic comparisons are essential to drawing out universal and specific processes of word processing among scripts, and thus to reach a broader understanding of reading processes. On the modeling side, the initiatives proposed so far therefore need to take into account that a substantial number of alphabetical scripts are based on more than 26 letters.

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[2] In this experiment, as in Experiment 1, the results were similar when the primes and targets shared their phonological form (e.g., *u*/*û*, *taper*/*tâper*) and when they did not (e.g., *e*/*ê*, *paire*/*païre*).

**Author note** This study was partly funded by the National Belgian Fund for Scientific Research (grant n° 19536975). All the materials, raw data, and scripts for the analyses and stimulation are available on the Open Science Framework: https://osf.io/w28fg/.

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