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Prelexical phonologic computation in a deep orthography: Evidence from backward masking in Hebrew

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Prelexical phonological computation of print was examined in Hebrew orthography using backward masking. Target words were masked by homophonic, phonologically similar, or phonologically dissimilar nonwords. Phonological similarity between masks and targets affected detection in a nonlinear fashion: No differences were found between homophonic and phonologically similar masks, whereas phonologically dissimilar masks hindered identification dramatically. This suggests that representations computed in brief exposures are coarse grained and not detailed enough to capture fine phonetic differences.

Theories of word recognition differ in the role they assign to phonological processing in the course of perceiving printed stimuli. Whereas some theorists suggest that phonological recoding is a late component of print processing, occurring mainly for low-frequency, regular, or consistent words (e.g., Coltheart, 1980; Paap & Noel, 1991; Seidenberg, Waters, Barnes, & Tannenhaus, 1984), other theorists contend that the recovery of phonological information from print is the primary cognitive operation in visual word perception (e.g., Frost, 1995; Katz & Frost, 1992; Van Orden, Johnston, & Halle, 1988).

One necessary question to be examined in the present context concerns, therefore, the *mandatory* aspect of phonological recoding: Is a phonological code a necessary product of processing printed words, even though the explicit pronunciation of their phonological structure is not required? There is no argument that certain tasks might elicit phonological recoding even if they do not consist of overt naming. Thus, rhyming judgments, positive lexical decisions to pseudowords that sound like words, or matching print to speech or to picture names will all probably result in a phonological code. The hypothesis that phonological recoding is automatic is much stronger. It posits that the computation of phonology is a nonstrategic process that occurs as the rule, and not as the exception. Consequently, phonological processing should be demonstrated in tasks in which a phonological output had no obvious role.

Perfetti and his colleagues (Berent & Perfetti, 1995; Perfetti & Bell, 1991; Perfetti, Bell, & Delaney, 1988) have examined the automaticity of phonological recoding using backward masking. In the backward masking paradigm, a target word is presented for a very short duration (usually, 15–30 msec). The target word is followed (i.e., masked) by a pseudo-word that appears for 15–60 msec and is then replaced by a simple pattern mask. The pseudoword that masks the target can be phonemically similar to the target (e.g., *raik* masking the target *rake*), graphemically similar (e.g., *rafk* masking *rake*), or a control mask (e.g., *nolt* masking *rake*). The subjects' task is to report in writing what they have perceived. Typically, subjects perceive but one event, the target word, and do not have any conscious recollection of the nonword mask. Even the target word is not always perceived, given its brief exposure, and is reported in full only in part of the trials. In spite of the fact that the nonword masks are not consciously perceived, they could, in principle, exert some influence on the detection of the target. This is because the short exposures characteristic of the masking paradigm allow the on-line processing of the nonword masks to merge with the incomplete processing of the word targets. Perfetti and his colleagues consistently found that nonwords that were phonemically similar to the targets they masked produced better identification rates than did graphemically similar controls (Perfetti & Bell, 1991; Perfetti et al., 1988; and see Perfetti, Zhang, & Berent, 1992, for a review). This outcome suggests that the phonologic information extracted from the masks may contribute to the reinstatement of the phonological properties of the targets.

The strength of the backward masking paradigm in testing whether phonological recoding is mandatory lies, therefore, in its presentation of nonwords and its use of brief exposures. Since nonwords are not lexical units, any influence they might have on the perception of the targets reflects a fast, self-launched, *prelexical* process. More important, the masking procedure makes it less likely that the observed facilitation is the product of some conscious, retrospective appreciation of the relationship be-

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tween the mask and the target. One caveat of regular phonological priming procedures is that the phonological manipulation (e.g., introducing pseudo-homophones in the list, etc.) is consciously perceived by the subjects and thereby influences their strategic responses to the targets. The masking of the target by the immediate presentation of the nonword mask has the advantage that the subjects' responses are less likely to be influenced by strategic processes that rely on conscious awareness. The automaticity of phonological recoding as revealed by the backward masking paradigm has been recently challenged by Verstaen, Humphreys, Olson, and d'Ydewalle (1995), who demonstrated that phonemic effects in backward masking may disappear if the stimuli list is exclusively composed of homophones. Although this outcome suggests that even unconscious processes may not be immune to some strategic control, it does not contravene the hypothesis that phonological recoding is an autonomous process that is launched as a rule, and not as the exception.

Results supporting the automatic and prelexical computation of phonology from print stem primarily from studies conducted in English. Attempts to replicate these findings in a deeper orthography like Chinese have not produced unequivocal results (Perfetti & Zhang, 1991; Tan, Hoosain, & Peng, 1995; Tan, Hoosain, & Siok, 1996). Perfetti and Zhang did not find a facilitatory effect of homophonic masks on target detection. They attributed the failure to obtain evidence for prelexical phonetic computation in Chinese to the nonalphabetic characteristics of Chinese orthography (see Perfetti et al., 1992, for a review). By this view, phonologic activation should be constrained by the limits of a given writing system in conveying prelexical phonological information. It should be evident in shallow orthographies like Serbo-Croatian or even English or French (see, e.g., Ferrand & Grainger, 1993; Lukatela & Turvey, 1990), but much less so in orthographies that do not convey full phonological information, like Chinese. Recently, however, Tan et al. (1995) have demonstrated that presemantic phonological computation of Chinese characters can be shown in Chinese as well, provided that the exposure durations of targets and masks are extended (60 and 40 msec, respectively). However, in contrast to results in English (e.g., Berent & Perfetti, 1995), the computation of a phonological code occurs through a character-as-a-whole to sound-as-a-whole association (Tan et al., 1996).

In this context, Hebrew provides an interesting case for examining the role of prelexical computation of phonology. In Hebrew, letters represent mostly consonants, while most of the vowels can optionally be superimposed on the consonants as diacritical marks ("points"). The diacritical marks, however, are omitted from most reading material, and can be found only in poetry, children's literature, and religious scriptures. Since different vowels may be inserted into the same string of consonants to form different words or nonwords, unpointed Hebrew print cannot specify a unique phonological unit. Therefore, a printed consonant string is always phonologically ambiguous and often represents more than one word, each with a different meaning. Some vowels, however, (mainly /o/, /u/, /i/) may be represented in print not only by points but also by letters. These letters are not always used, and are often considered optional by the writer.[1] When they are used, however, the phonologic structure of the word can be often assembled almost as easily as it can be assembled in pointed print. The depth of Hebrew orthography is evident in yet another feature. Several consonants (mainly, /k/, /t/, /x/, /v/, and glutal /a/), have two letters representing them. In ancient Hebrew, these letters depicted a phonetic distinction that is absent in modern Hebrew. This feature is of immediate relevance to the backward masking paradigm because Hebrew pseudo-homophones can be created mainly by interchanging these consonantal letters.

In a recent review, Perfetti and his colleagues have suggested that in its effect, Hebrew is potentially similar to Chinese (Perfetti et al., 1992). By this view, because vowel information is missing in Hebrew print, the complete phonetic structure of the printed word cannot be computed prelexically, and therefore phonemic facilitation might not emerge in the backward masking paradigm. Nevertheless, recent findings by Berent and Perfetti (1995) challenge these predictions. In their two-cycle model of phonetic computation, Berent and Perfetti suggested that in English, consonantal information is computed first to provide a skeletal impoverished phonological structure. Only during a second cycle is the vowel information computed and incorporated into the skeletal phonological code to produce a fully specified phonetic structure. The lag between consonant and vowel information stems from the ambiguity of printed vowels in English orthography. By this view, the two-cycle model would predict that phonemic facilitation should indeed emerge using backward masking in Hebrew if the nonword masks and the target words contained homophonic consonants that are represented by two different letters (e.g., /t/ represented by the letters ת and ט). This is because the consonants that are the core of Hebrew print are computed in a first cycle.

The aim of the present study was to investigate this possibility. Any evidence for prelexical phonetic computation in a deep orthography like unpointed Hebrew would provide strong support for the mandatory nature of phonological recoding and would be in accordance with the two-cycle model proposed by Berent and Perfetti (1995). It would show that even in an orthography that does not provide full phonological information in print, some automatic prelexical computation occurs. A failure to obtain evidence for phonemic effects in the backward masking paradigm would support the view that phonologic information in unpointed Hebrew is mainly postlexical, and that phonologic recoding occurs only when a complete and detailed phonetic representation can be computed from print.

The Experiment

Similar to the original procedure of Perfetti et al. (1988), the experiment consisted of a brief presentation of target words that were masked by nonwords. However, there is a marked difference between the English and the Hebrew stimuli because of the special characteristics of unpointed Hebrew print. Consider, for example, the English target word *rake*. In the backward masking paradigm, the homophonic (phonemic) nonword mask for *rake* would typically be *raik*, whereas the graphemic mask would be *rafk*. The effects of phonemic and graphemic masks would be then evaluated relative to a control condition like *nolt*. The homophonic nonword mask is therefore produced by changing the vowel letter *a* into *ai*, which represents consistently the vowel /ay/ in English. This is because the inconsistency in spelling patterns in English orthography stems mainly from the inconsistency in vowel representation. In Hebrew, on the other hand, the inconsistency in spelling patterns concerns consonants only. Thus, nonword homophonic masks would consist of letter strings in which one consonant letter is replaced by another letter representing the same consonant.

Consider for example the target word כפית. It is pronounced /kapit/, meaning a "teaspoon" (/kapit/ is printed with four letters only, *KPIT*, because the first vowel /a/ is not conveyed in print, whereas the final vowel *I* is represented by the letter vowel י). The masking paradigm takes advantage of the fact that the phoneme /t/ in Hebrew may be represented by two letters, ת and ט. Therefore, the homophonic mask for כפית will be כפיט. However, the nature of the proper graphemic mask in Hebrew is a crucial methodological and theoretical issue. In English, the graphemic mask differs from the target by one letter only, but nevertheless creates a nonword that is phonetically distinct from the target. The question is, how distinct it should be? Since the phonemic mask is compared with the graphemic mask to evaluate its superiority in reinstating the target, the phonetic contrast between the phonemic and graphemic masks determines almost exclusively the size of the effect, and consequently the probability of detecting it. In the English example, *rafk* (/rafk/ differs from *raik* (/rayk/) by at least two phonemes, one a vowel, the other a consonant. A fast prelexical computation would therefore produce very distinct phonetic representations for the two masks, creating sharp contrast between the phonemic and graphemic conditions. In Hebrew, on the other hand, this contrast might be compromised because vowels are usually not represented in print, and the two masks would differ by one consonant only. Using the above example, if כפית (/kapit/) is masked by כפיז (/kapiz/), the graphemic mask would be quite similar phonetically to the phonemic mask. Because, in general, the advantage of the phonemic over the graphemic mask in the backward masking paradigm is quite small to begin with, such shallow contrast between two masks might result in undistinguishable detections rates for both experimental conditions. This problem raises a more theoretical issue concerning the nature of the prelexical computation process in the backward masking paradigm. Mainly, it questions whether the phonologic representations computed in this paradigm are detailed enough to capture fine phonetic differences between masks and targets, or whether they are impoverished and coarse grained.

To examine this question, we introduced two additional graphemic masking conditions that differed in their phonological similarity to the targets. In the first, the consonant letter was replaced by a "neutral" grapheme—a pound sign (#). Thus, instead of replacing the target consonant by another consonant, the replacing character was "neutral," and some parts of the resulting phonetic representation therefore remained underspecified. We hypothesized that with the very brief exposures used in the backward masking paradigm, this mask would probably result in an impoverished phonological representation in which one consonant remains undefined, but is nevertheless quite similar to the graphemic or phonemic masks. If the paradigm is not sensitive to minute phonetic differences resulting from a single consonant substitution, then the neutral mask would result in a performance similar to that with the regular graphemic mask. However, to mimic the English paradigm, a greater phonetic contrast between graphemic and phonemic masks is required. This can be easily achieved by introducing another form of graphemic mask that substitutes the vowel letter with a consonant letter. For example, כפזת differs from כפית by one letter (the mid-letter ז (/z/), substituting the vowel letter י). However, the most probable pronunciation for כפזת is /kapezet/, which differs from /kapit/ quite significantly.[2] The present experiment included, therefore, these two types of graphemic masks.

Note that if prelexical phonetic recoding does not occur, no differences in performance are expected to emerge between the phonemic mask and between any of the above graphemic masks. This is because "graphemically," *all* masks consist of a single letter substitution, and they differ only in the phonetic representations created by each of the letter substitutions. This, however, would not have a psychological reality if the nonword mask had not been phonologically recoded. Thus, the comparison between the three graphemic masks (neutral, phonetically similar, and phonetically dissimilar) allows an additional test of the hypothesis that prelexical phonologic recoding occurs mandatorily even in a deep orthography like unpointed Hebrew.

Method

Participants. The participants were 40 undergraduate students at the Hebrew University, all native speakers of Hebrew, who participated in the experiment for course credit or for payment.

Stimuli and Design. Sixty target Hebrew words, three to five letters long, containing three to six phonemes, were employed. The words were presented unpointed, but were all unambiguous since they could be read as meaningful words in only one way. Each target could be masked by five possible masks: (1) a phonemic mask in which one consonant letter of the target was replaced by the homophonic letter representing the same phoneme; (2) a "neutral" mask, in which the consonant letter was replaced by a pound sign (#); (3) a phonetically similar graphemic mask, in which the same consonant letter as above was replaced by another consonant letter; (4) a phonetically dissimilar graphemic mask, in which a vowel letter was replaced by a consonant letter to create a nonword differing significantly from the target in its phonetic structure, yet preserving the same graphemic similarity with the phonemic mask; and

(5) a control mask that differed from the target in all of its letters. The position of the substituted letters within the target words could be initial, middle, or final. Table 1 presents an example of the stimuli employed in each of the five experimental conditions.

The 60 target words were divided into five lists, each list containing 12 words in each condition. The stimuli were rotated within the five conditions in each list by a Latin-square design. Subjects were randomly assigned to each of the five lists, allowing each subject to provide data points in each condition, yet avoiding stimulus repetition effects.

Procedure and Apparatus. The experiment was conducted on an IBM 486 computer. The software used for presentation of stimuli was the DMASTR display system developed by K. I. Forster and J. C. Forster at the University of Arizona. Each trial consisted of three visual events. The first was the target word, appearing for 16 msec. The target was immediately followed by the nonword mask, with an exposure duration of another 16 msec. The nonword mask was in turn immediately followed by a pattern mask that remained on the screen until the next trial. All visual stimuli were centered in the viewing screen and were superimposed on the preceding stimuli. Although only one Hebrew square font was employed, two versions of this font, which differed in their relative size, were used.[3] Targets were always presented in the smaller font (20% smaller than the masks). This guaranteed complete visual masking of the targets by the masks, and also made the targets and the masks physically distinct stimuli.

Subjects were tested in a dimly lit room and were seated 70 cm from the computer screen. When they were ready, they initiated the presentation of each trial by pressing the space bar. After each presentation, they were required to write on a response sheet the word they had perceived. After writing the word they identified, they again pressed the space bar to initiate the onset of the next trial. After 30 practice trials, all 60 experimental trials were presented in one block.

Results

The number of correct identifications (the full recovery of all of the word letters) in each experimental condition was calculated for each subject. Figure 1 presents the percentage of correct responses in the five masking conditions.

The results were subjected to a one-way analysis of variance (ANOVA) with the factor of mask type. The effect of mask was significant [$F(4,156) = 26.7$, $MS_e = 2.7$, $p < .001$]. Planned comparisons revealed that the poorest identification level was in the control mask condition, which differed from all other masks. The phonetically dissimilar graphemic mask produced better performance than did the control condition [$F(1,156) = 3.9$, $p < .05$]. However, identification was significantly better with the phonemic mask, the phonetically similar graphemic mask, and the neutral mask relative to the phonetically dissimilar graphemic mask [$F(1,156) = 24.4$, 33.0, 34.0, respectively]. These three masks produced very similar identification rates and did not differ from one another ($F < 1.0$ for all contrasts).

Table 1
Examples of Stimuli Employed in the Five Masking Conditions

		Graphemic Masks			
	Phonemic	Neutral	Phonetically Similar	Phonetically Dissimilar	Control
Target	כפית	כפית	כפית	כפית	כפית
Mask	כפיט	כפי#	כפיז	כפזת	צבלד
Phonetic structure	/kapit/	/kapi-/	/kapiz/	/kapezet/	/zablad/

Discussion

The present study employed the backward masking paradigm to investigate the extent of automatic prelexical phonological recoding in a deep orthography like unpointed Hebrew. We manipulated the graphemic and phonemic characteristics of the nonword masks to examine the ability of various phonetic representations to restore the phonetic properties of the target.

The results showed better detection in all experimental conditions relative to the control condition. Thus, the phonemic mask as well as the three graphemic masks increased the probability of detecting the targets relative to the control mask, which did not share with the targets any letters or phonemes. There were, however, marked differences in the efficacy of the various graphemic masks in improving target identification. Whereas the phonemic mask, the phonetically similar graphemic mask, and the neutral mask were equally effective in restoring the targets, the phonetically dissimilar mask yielded performance that was more similar to that in the control condition. All phonemic and graphemic masks were graphemically similar because they differed from the target by one letter slot. They differed only in their phonetic resemblance to the targets. Thus, any differential effect these nonwords would have on masking the target should be considered as evidence that prelexical phonologic computation has occurred.

Two findings are of considerable interest for assessing the automaticity of phonological recoding of printed words. First, the lower detection rates of targets in the phonetically dissimilar mask relative to the other masks strongly suggests that prelexical phonological computation occurs in a deep orthography like unpointed Hebrew. Although part of the vowel information was not conveyed in the orthographic letter string, the internal phonetic structure of the nonword mask and its decreasing resemblance to the targets had a strong effect on detection rates. Because the phonological structure of the phonemic mask, the phonetically similar graphemic mask, and the neutral mask better matched the phonological structure of the targets, performance in these experimental conditions was significantly improved.

Equally interesting, however, is the similar (almost identical) performance in these three conditions. This outcome suggests that the phonological representation computed from the masks was coarse grained. Thus, the exposure parameters characteristic of the backward masking paradigm seem to produce impoverished phonological representations of the masks in such a way that slight differences in the nonword's phonological structure have no effect on the probability of reinstating the targets. Note that the graphemic masks used by Perfetti et al. (1988) were mostly phonologically dissimilar to the targets. That is, they differed phonetically from the targets often by two vowels and a consonant (e.g., *made–mayd* vs. *made–mago*). It is possible that smaller phonetical resemblance might not have produced the phonemic advantage obtained by Perfetti and his colleagues. This conclusion is further supported by the similar (although significantly different) poor performance in the phonetically dissimilar relative to the control conditions. At a certain point, phonetically dissimilar masks hinder performance without dramatic differences between degrees of dissimilarity.

What exactly is computed in the impoverished phonological representation needs further investigation. As the stimuli in our experiments were unpointed, the nonword masks could be read in several possible ways with different vowel configurations, given the permissible phonological word patterns in Hebrew. Thus, our study cannot provide unequivocal predictions concerning the efficacy of a specific nonword mask in reinstating its respective target. However, it is fairly clear that the substitution of a vowel by a consonant that could be coarticulated with yet another vowel created in the phonologically dissimilar condition a phonological contrast that was distant enough to diverge from the target's representation, thereby reducing targets' detection rates.

The finding that the phonological representation computed from print is initially impoverished and coarse grained is supported by studies in Hebrew (Frost, 1995) and English (Berent & Perfetti, 1995), which suggest that at very brief exposure durations, computed representations contain only partial phonological information that is mainly consonantal. The underspecification of phonological representations is an important theoretical construct in models of lexical search. Because lexical information is maximally rich, coarse-grained (or underspecified)

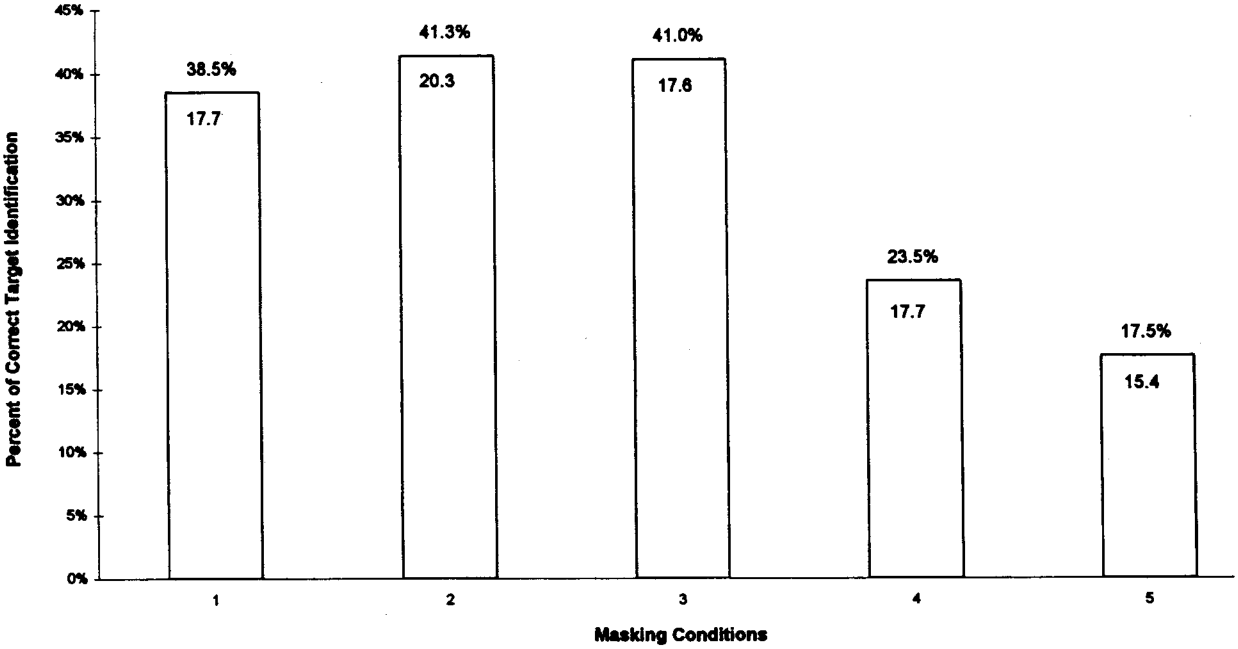

Figure 1. Percent of target identification with five masking conditions (*SDs* within bars). 1, phonemic; 2, neutral; 3, phonologically similar; 4, phonologically dissimilar; 5, control.

access representations that match the detailed lexical representations only in part allow the very fast search that is characteristic of visual word recognition (see Frost, 1996, for a theoretical discussion). Coarse-grained phonology is also accommodated by resonance models by considering the correlational structure of spelling to phonology in a given orthographic system (Van Orden & Goldinger, 1994, 1996).

In conclusion, our results suggest that an automatic process of prelexical phonological computation may occur in a deep orthography like unpointed Hebrew, which is fundamentally different from English. This process produces an impoverished phonological representation that includes mostly consonantal information. The vowel information is probably available in a second cycle from top-down lexical information (Berent & Perfetti, 1995; Frost, 1995). Our findings, therefore, provide additional support for a strong phonological model of reading that considers phonological computation a primary stage of visual word processing, regardless of the depth of the orthography.

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NOTES

1. The origin of vowel letters reflects an ancient distinction between different forms of vowels that differ mainly in their duration, long vowels being represented by letters. This distinction, however, has no true phonetic reality in modern Hebrew. There are specific grammatical rules that determine when a long or a short vowel should be employed, and consequently these rules specify whether the vowel should be printed with a letter or not. However, because the different printed forms of those vowels do not reflect a phonetic distinction in the spoken language, these rules are often not known to the adult writer, and the inclusion of vowel letters is sometimes optional. Consequently, many words may appear with or without the vowel letters in different texts or within the same text (see Shimrom, 1993, for a discussion).

2. Because the printed consonants can, in principle, take any of the five vowels of Hebrew, the nonword mask / כפאח / can be read in many ways. Nevertheless, as all Hebrew words are composed of a root morpheme and an infixed phonological word pattern, the possible readings of a consonant string are constrained by the permissible word patterns of Hebrew, and by their relative frequency.

3. If the primes and the targets are not cognitively separated, the masked presentation consists virtually of displaying the mask and the target as *one* prolonged single presentation. Practically, such a display procedure is equivalent to measuring latencies to the targets from primes rather than from targets onsets. In English, the separation of primes and targets was often achieved by using uppercase and lowercase scripts. Although Hebrew has two forms of scripts (regular print and cursive), the cursive script is not often used in print, and therefore we adopted the manipulation of size rather than form.

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