EARLY MORPHOLOGICAL DECOMPOSITION: THE EFFECT OF DERIVATIONAL GAPS*

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Using masked priming, this study examines the impact of morphological gaps on the decomposition of multiply suffixed words during visual word recognition. We investigate the morphological decomposition of extant English words under two conditions. The Gap condition consists of two-suffixed words, e.g., *historical*, in which two suffixes separately attach to the root *history* and yield two extant words (i.e., *historic* and *historical*). The NoGap condition consists of two-suffixed words, e.g., *biblical*, whose first suffixation does not result in an existing English word (i.e., **biblic*). We observe similar priming effects across the two conditions. These results suggest that the two suffixes are stripped from their root in both conditions. Crucially, words in the Gap condition show significantly longer reaction times (RT). We attribute these longer RTs to the lack of a lexical representation for the decomposed intermediate form (e.g., **biblic*). Overall, these findings suggest that although morphological decomposition in masked priming is prelexical, word access is still sensitive to paradigmatic structure.

1. Introduction

Visual masked priming findings suggest evidence for an early parsing mechanism. This mechanism decomposes (even pseudo-) affixed words into their morphemic constituents (e.g., *excitement* is decomposed into *excite* + *ment*; see Rastle et al. 2000, 2004; Longtin and Meunier 2005; Lehtonen et al. 2011; Crepaldi et al. 2016). This decomposition occurs at a prelexical level, prior to contact with the lexicon (Rastle et al. 2000, 2004).

Here, we examine the recognition of two-suffixed complex words and the impact of morphological gaps on decomposition. For example, {-ic} attaches to the root noun *history* to create the adjective *historic*. Subsequently, {-al} can further attach to derive *historical* (e.g., histor(y) + {ic} + {al}, econom(y) +{ic} + {al}); however, there are instances where suffixation does not result in an existing English word. For example, the attachment of {-ic} to roots *whimsy* and *bible* yields nonwords (i.e., **whimsic* and **biblic*). This is despite the fact that the subsequent suffixation of {-al} creates real English words. In both descriptive and theoretical work (e.g., Malkiel 1966, Bauer 1988, Bauer et al. 2013, Stump 2019), words such as *whimsical* and *biblical* have been referred to as having a paradigmatic/derivational gap: They are missing the intermediate deriva-

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tive (i.e., the form made by the initial suffixation of {-ic}). The derivational steps of *whimsical* and *biblical* are provided in (1) and (2), respectively.

(1) *whimsy* > **whimsic* > *whimsical*
(2) *bible* > **biblic* > *biblical*

Using visual masked priming (Forster and Davis 1984, Forster 1998), we examine the decomposition of complex, tri-morphemic words with paradigmatic gaps (henceforth Gap words; e.g., *biblical*) compared to those with no paradigmatic gap (henceforth NoGap words; e.g., *historical*). As noted above, previous results suggest that decomposition occurs with masked priming. Therefore, more precisely, we want to explore whether this decomposition process is sensitive to the presence of gaps in the morphological paradigm. Apart from a few previous studies (e.g., Longtin and Meunier 2005, Meunier and Longtin 2007, Kazanina et al. 2008, Schuster 2018), the primary concern of most (masked) priming studies has been the morphological decomposition of single-affixed words.

In visual masked priming, a visual prime is presented for an extremely brief length of time (< 50 ms). This prime is preceded by a visual masker and followed by the target word to which participants typically make a lexical decision. The brief prime duration and presence of the mask renders the prime imperceptible to most participants. Based on previous findings, the presentation of a prime facilitates target recognition. Using masked priming, Rastle et al. (2000) argued that morphological decomposition (at least under masked conditions) is blind to the semantic composition of morphologically complex words. Priming is reported to occur despite the lack of a semantic relationship between the prime and target. Words such as *release* or *corner* were erroneously decomposed into {re + lease} and {corn + er} and prime *lease* and *corn*, respectively. Furthermore, this priming effect was not statistically different from the priming effect in semantically transparent primes and targets (e.g., *farmer*-FARM). Finally, control conditions demonstrate that this priming effect cannot be attributed to orthographic overlap alone (e.g., *brothel* did not prime *broth*; {-el} is not an English suffix). These results are taken to support affix-stripping models (e.g., Taft and Forster 1975), which claim that at a prelexical stage, words are decomposed into their morphological constituents and this decomposition is blind to lexical semantics. Subsequently, decomposition facilitates target (root) recognition. This, in fact, explains why we observe priming. These findings have been replicated extensively in a variety of languages (see Rastle and Davis 2008 for a review).

Considering the fact that in words with a paradigmatic gap, the attachment of the first suffix yields a pseudo-affixed word (e.g., **biblic* in *biblical*), the examination of these words becomes important. We also indirectly test if their intermediate form (i.e., the form with the first suffix) is decomposed or not. Table 1 illustrates examples of words with and without lexical gaps.

Table 1. Examples of Gap and NoGap items

Gap			NoGap		
Whole Word (Prime)	Intermediate Form	Root (Target)	Whole Word (Prime)	Intermediate Form	Root (Target)
biblical	*biblic	bible	historical	historic	history
characteristic	*characterist	character	capitalist	capitalist	capital
libertarian	*libertary	liberty	disciplinarian	disciplinary	discipline

In this study, we approach the question of affix stripping. We have two questions. First, are the affixes in both conditions stripped from the root? If affixes are stripped regardless of whether there is a gap in the paradigm, root access should demonstrate similar priming effects in both conditions (Meunier and Longtin 2007, Schuster 2018). Second, does the missing intermediate form (Gap condition) affect priming and target access? If there is no such effect, we expect similar priming effects for words with paradigmatic gaps and those with no paradigmatic gaps.

In the current masked priming experiment, primes are whole words and targets are roots. As in Table 2, each target (root) is preceded once by a related whole word prime and once with an unrelated whole word prime as a control. Note that the primes in our experimental items are real words of English, and they all have a similar structure, i.e., root + suffix + suffix. Crucially, we are not directly testing the intermediate forms: the primes are the whole word forms and targets are the roots.

Table 2. Conditions and examples

Prime	Target
Related: whimsical	WHIMSY
Unrelated: changeability	WHIMSY
Related: historical	HISTORY
Unrelated: regionalism	HISTORY

In most previous masked morphological priming studies, reaction times (RT) are the dependent variable where differences are principally observed (Rastle and Davis 2008). If the paradigmatic gap impacts decomposition and hence the access of a Gap word, we expect different RTs between conditions.

2. Materials and method

2.1 Collecting stimuli

Eighty-four pairs (forty-two pairs per condition) were selected from the Corpus of Contemporary American English (COCA; Davies 2009, 2010). These items consisted of five affixes: {-ical}, {-ation}, {-arian}, {-istic} and {-icity}. All words were two-suffixed,

and we controlled all roots to be phonologically transparent after suffixation.[1] We also controlled all roots to be free lexical items (i.e., excluding words such as *identical* with the bound root *ident*). We also excluded words that have an ambiguous root, such as *foundation* that has a root (i.e., *found*), which conveys the past tense inflection of the verb *find*. Whole words and roots were also controlled for length and frequency across conditions. We ran independent samples t-tests between conditions, and the results showed no significant differences between the length and the frequency of the roots or between the length and frequency of the whole words. Table 3 presents the test statistics of these comparisons. The frequency counts are represented by two values: The smaller numbers are the mean of relative frequency counts per 1 million words, and the larger numbers in parenthesis are the mean of frequency based on the COCA word count.

Table 3. Test statistics for length and frequency of roots and whole words across the two conditions prior to participant norming (n = 84 prime-target pairs).

Comparison	p-value	df	t	$\bar{x}$ Gap	$\bar{x}$ NoGap
Root Length: Gap-NoGap	0.22	82	1.21	7.30	6.80
Word Length: Gap-NoGap	0.48	0.69	81.96	11.38	11.09
Root Frequency: Gap-NoGap	0.31	67.40	-1.00	37 (20833)	53 (29818)
Word Frequency: Gap-NoGap	0.27	81.34	1.09	10 (5382)	7 (3762)

To ensure that the intermediate gaps in our Gap items really were gaps in English, we performed an online lexical decision experiment using PCIBEX Farm (Zehr and Schwarz 2018). We asked 30 monolingual English speakers (age range: 18-32 years) for acceptability judgments of the intermediate forms in both conditions. In this experiment, only intermediate forms were presented, e.g., **biblic*, *historic*. Participants were instructed to decide via keypress if a string of letters on the screen is a word of English or not. Participants were compensated CAD $5.41 for their time. Informed consent was obtained prior to the experiment.

Based on the results of the lexical decision experiment, we considered the top 32 words with 'yes' responses in the NoGap condition, and we considered the 32 words with the highest number of 'no' responses in the Gap condition. We removed three pairs in each condition because they did not conform to our norming criteria. Therefore, the final list contained 58 pairs, 29 pairs per condition.

[1] The phonological changes in our items were limited to final vowel deletion (e.g., libertarian-LIBERTY), vowel shortening (e.g., typical-TYPE, cyclical-CYCLE) and vowel deletion (e.g., registration-REGISTER).

2.2 Main experiment stimuli

For the main experiment, we examined the 58 prime-target pairs, 29 in each condition. Because of the removal of some words from our initial eighty-four pair list, we had to retest the final 58 pairs for their length and frequency. Also, the primes and targets across the Gap and NoGap conditions were tested for their length and frequency. Therefore, the comparisons were in two dimensions: One comparison was between the two conditions, i.e., Gap and NoGap in the length and frequency of their whole words (primes) and roots (targets). The other comparison was between prime conditions (i.e., Related and Unrelated) in their length and frequency. The results showed no significant differences between the items with respect to these variables (results reported in Table 4 and 5). As indicated above, the frequency counts are represented by two values. The smaller numbers are the mean of relative frequency counts per 1 million words, and the larger numbers in parenthesis are the mean of frequency based on the word count of COCA.

Table 4. Test statistics of length and frequency of roots and whole words across the two conditions after participant norming (n = 58 pairs).

Comparison	p-value	df	t	$\bar{x}$ Gap	$\bar{x}$ NoGap
Root Length: Gap-NoGap	0.55	55.29	0.59	7.24	6.96
Word Length: Gap-NoGap	0.78	55.88	0.27	11.51	11.37
Root Frequency: Gap-NoGap	0.16	35.96	-1.41	32 (18110)	61 (34293)
Word Frequency: Gap-NoGap	0.50	52.11	0.66	9 (4777)	7 (3660)

Table 5. Comparison of prime length and frequency based on the prime type

Comparison	p-value	df	t	$\bar{x}$ Gap	$\bar{x}$ NoGap
List1 Prime Len: Related-Unrelated	0.69	51.93	0.39	11.53	11.35
List2 Prime Len: Related-Unrelated	0.98	55.29	0.02	11.36	11.35
List1 Prime Freq: Related-Unrelated	0.89	41.83	-0.13	9 (4867)	9 (5215)
List2 Prime Freq: Related-Unrelated	0.27	35.12	-1.10	6 (3425)	12 (6524)

We also added 58 nonword targets. The same nonwords were used in both lists. The primes of these nonwords were all real two-suffix English words and were the same across the two lists. Nonword targets were based on English words with two or three segment changes. In summary, we had a 2 × 2 design with the factors Condition (Gap, NoGap) and Relatedness (Related, Unrelated). The design is illustrated in the Table 6. The dependent variable of interest is RT, although we also report the proportion correct.

Table 6. Conditions and examples

Condition	Prime	Example	Intermediate form
Gap (n = 29)	Related	whimsical-WHIMSY	*whimsic
	Unrelated	changeability-WHIMSY	
NoGap (n = 29)	Related	historical-HISTORY	historic
	Unrelated	regionalism-HISTORY	
Nonword (n = 58)	Real Word	flexibility-MELOUD	

Regardless of the condition, we expect faster mean RTs for targets preceded by a related prime compared with targets preceded by an unrelated prime (priming main effect). Considering the conditions, as stated above, if the existence of paradigmatic gaps influences decomposition and root access, we expect reaction time differences between the two conditions.

2.3 Participants

Thirty-six participants (age range:18-22 years, 23 female and 13 male) were recruited from the University of Toronto Scarborough. All participants were native speakers of English and had normal or corrected to normal vision. Participants were all dominantly right-handed and compensated with course credit or $5.00. Participants provided written informed consent prior to the experiment.

2.4 Procedure

Each trial included a mask, a prime and a target visual stimulus. All targets were monomorphemic roots and all primes were the whole word (i.e., trimorphemic) forms. Primes were either morphologically and semantically related (e.g., whimsical-WHIMSY) or unrelated (e.g., changeability-WHIMSY). We made two lists based on having related and unrelated primes so that participants saw each word only once. Hence, for one single word, a participant saw only one type of prime (i.e., either related or unrelated). For example, in List 1, *whimsy* was paired with an unrelated prime (changeability), and in List 2, it was paired with its related prime (whimsical).

Participants were tested in separate cabins in the Computation and Psycholinguistics Laboratory (CAP LAB) at the University of Toronto Scarborough. Stimuli were randomized and presented with DMDX (Forster and Forster 2003). Participants were told that in each trial after a brief fixation string of octothorpes, they will see a string of letters in the center of the screen. They were told that their task is to respond whether the letter-string they see is an English word or not. Participants used a four-button USB button box (The Black Box Toolkit, Sheffield UK) to respond. For 'yes' answers they were told to press button '4' with their dominant hand (i.e., their right hand given that all participants were right hand dominant), and for a 'no' response, they were instructed to press '1'. Participants were encouraged to respond as quickly and as accurately as possible. They were

also encouraged to ask for clarification if they had any questions. Participants were not told about the existence of the prime words.

Each trial began with a visual mask (i.e., ########) for 500 ms. The mask was followed by the prime presented in lower case for 37.5 ms. This is below the level of conscious awareness for most participants and within the range of prime durations known to elicit masked morphological priming (Rastle and Davis 2008). Finally, the target was presented in uppercase and remained on the screen until a participant made a lexical decision response or the trial timed out (2500 ms). The visual angle of the target was 9.41º. The inter-trial interval pseudo-randomly varied between 500 ms and 750 ms. Each session began with six practice trials.

3. Results

Two participants were removed due to low accuracy rates (< 70%). Overall accuracy across the remaining participants and conditions was 92%. Trials with RTs ±2.5 standard deviations from the individual participant's mean RTs were removed (3.62% of total trials). For the RT analysis, trials with incorrect responses were also discarded (102 trials, 5.69%). In total, 167 trials were removed (9.32% of the data).

3.1 Reaction times

Generally, words with related primes elicited faster reaction times than words with unrelated primes in both conditions. Targets in the Gap condition elicited slower RTs ($\bar{x}$ = 571 ms) than targets in the NoGap condition ($\bar{x}$ = 550 ms). See Table 7 and Figure 1.

Table 7. Means and Standard Deviations across conditions. Priming magnitude is the RT to the target when preceded by an unrelated prime subtracted from the RT to the target when preceded by a related prime.

Condition	Priming	RT mean (ms)	SD	Priming magnitude
Gap	related	559	181	- 23
Gap	unrelated	582	159	
NoGap	related	537	151	-25
NoGap	unrelated	562	145	

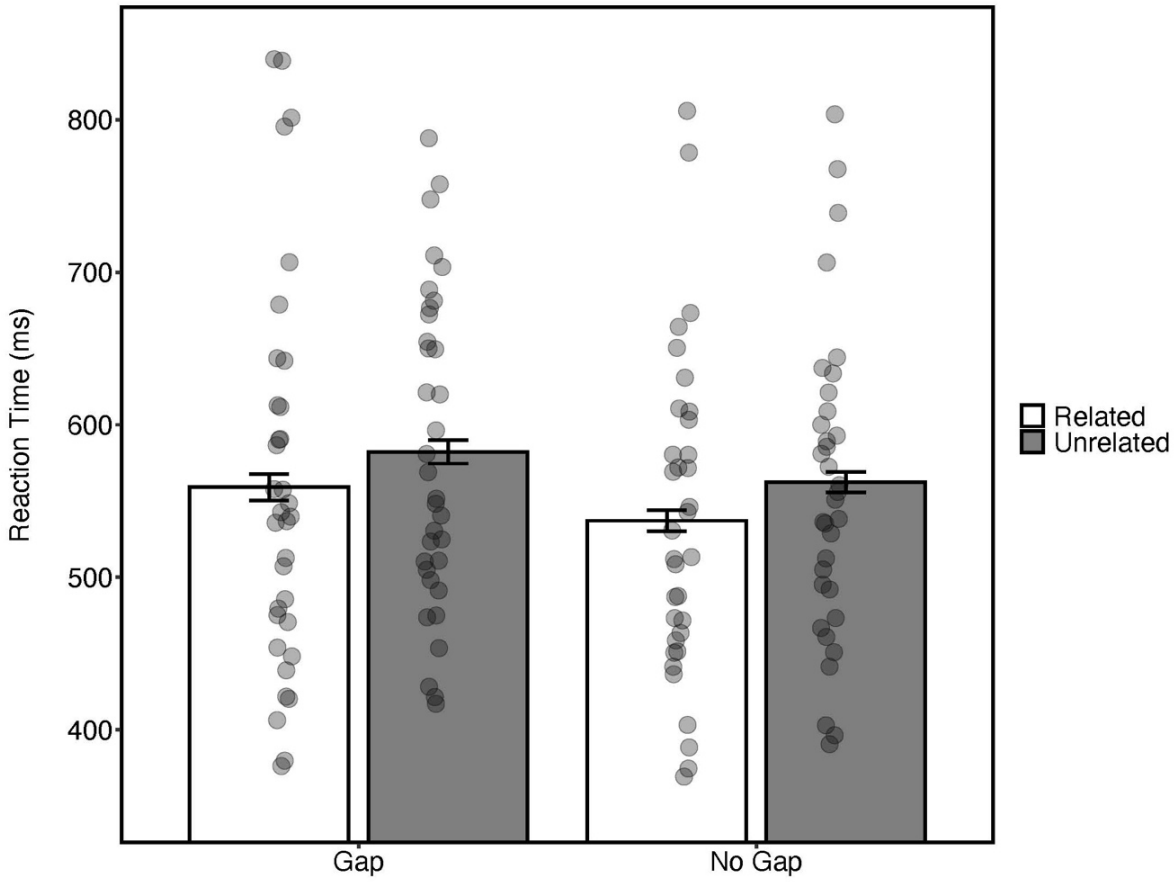

Figure 1. Reaction Time results to the target items. Error bars represent the standard error of the mean. Points represent individual participant mean RTs for each condition.

We submitted our results to a linear mixed effects model using the maximal random effects structure (Barr et al. 2013). We had the fixed effects Prime Relation (Related vs. Unrelated) and Condition (Gap vs. NoGap) and by-subject and by-item random intercepts. Our model also had by-subject random slopes for Condition and Prime Relation, and by-item random slopes for Prime Relation. The analyses demonstrated a significant effect of Prime Relation: (β =23.05, SE = 6.36, t(49.63) = 3.62, p-value < 0.001) and a significant effect of Condition: (β = 24.81, SE = 11.49, t(52.47) = 2.15, p-value < 0.05). We observed no Condition × Prime Relation interaction.

3.2 Accuracy

Targets in the NoGap condition also elicited slightly higher accuracy rates compared to the Gap condition. Table 8 provides the accuracy rates and standard deviation for each condition and priming type. Overall, the accuracy rate of the Gap words is numerically lower than for the NoGap words. Target responses in trials with a related prime also resulted in numerically higher accuracy rates.

Table 8. Accuracy rates

Condition	Priming	Accuracy	SD
Gap	related	0.94	0.23
Gap	unrelated	0.93	0.26
NoGap	related	0.96	0.18
NoGap	unrelated	0.95	0.22

4. Discussion

Here, we report the results of a single masked priming experiment that examined the decomposition of morphologically complex words. In general, the current experiment contained two conditions: Gap (trimorphemic words lacking the intermediate step in their derivation) and NoGap (trimorphemic words having the intermediate step between the root and the whole word) conditions. The goal was twofold. First, we wanted to explore if affixes are stripped from the root in both conditions. Second, we wanted to examine if the existence of paradigmatic gaps affects priming.

Results showed that targets preceded by related primes elicited significantly faster RTs than targets preceded by unrelated primes. This is the basic priming effect and is consistent with models of processing that postulate that morphologically complex words are decomposed during early word recognition (Rastle et al. 2000, 2004; Kazanina et al. 2008; Lehtonen et al. 2011; Gwilliams et al. 2015). We did not test whether the affixes themselves are decomposed separately or whether they are decomposed together; howev-er, given the significant priming effect in both conditions, it is somewhat more difficult to reconcile these results with theories of morphological processing that assume distinct whole word forms and undecomposed entries in the mental lexicon (Bradley 1979, Lukatela et al. 1980). If whole word forms were listed in the mental lexicon as separate and undecomposed entries, we should not have obtained a priming effect. Moreover, it is likely not the case that our observed priming effects are due to orthographic or phonolog-ical overlap between the prime and target. Crucially, orthographic overlap alone is insuf-ficient to result in priming in masked priming paradigms (see Rastle et al. 2000, 2004 for discussion).

Second, we obtained a significant effect of Condition. The Gap words in our study showed longer RTs compared to NoGap words. Crucially, this RT difference cannot be due to a stronger priming effect in the NoGap condition given that we found no Condition × Prime Relation effect (cf. Longtin and Meunier 2005, Schuster 2018). Our interpretation is twofold. First, consistent with previous findings that (even pseudo-) words are decomposed into their (potential) morphological units (Rastle et al. 2004, Longtin and Meunier 2005, Rastle and Davis 2008, Schuster 2018), in both conditions, affixes seem to be separately decomposed. Second, given that we found no interaction, we interpret the longer RTs in the Gap condition as an effect of the lexical gaps. We posit that in the NoGap condition, each decomposed form activates a lexical representation (i.e., an extant word; e.g., *historic-history*). By contrast, in the Gap condition, the decom-

posed intermediate form (e.g., **biblic*) does not activate any lexical representation (cf. Schuster 2018). Thus, participants expend more time linking that intermediate form to a word. Hence, target access is interrupted and takes longer in the Gap condition.

Crucially, words in the NoGap condition showed faster RTs compared with words in the Gap condition with both related and unrelated primes by 22 ms and 20 ms, respectively. The immediate question that arises is that if the target access is under the influence of root decomposition, how is it that we consistently observe faster RTs in the NoGap condition compared to the Gap condition. This occurs even when the primes are unrelated to the targets. If the targets were perfectly matched in their lexical variables, we expect there to be no inter-conditional RT differences when the primes are unrelated. These results shed light on the mechanism involved in the target access and provide evidence for the idea that word access might not solely be under the influence of prime presentation. One possible explanation is an effect of Morphological Family Size (MFS; Baayen et al. 1997, de Jong et al. 2000). Based on the MFS effect, the recognition of simple nouns is faster when these nouns have larger morphological families. We wanted to explore if these inter-conditional differences might be attributable to the MFS of our conditions.

We calculated the mean MFS for both conditions.[2] Crucially, the mean of our MFS differences is significant ($t(55.54) = -2.23$, $sd = 11.25$, $p\text{-value} < 0.05$). Thus, lexical decisions in the Gap condition might be less facilitated due to a smaller MFS; however, the family member differences in previous reports (de Jong et al. 2000) are considerably larger (~30) compared to our difference (7) and yet the RT advantage is similar to what we obtained (~20 ms). Therefore, the RT advantage in our study cannot be solely due to the MFS effect, and we still need to consider the effect of lexical gaps.

5. Conclusion

In this study, we examined the morphological decomposition of trimorphemic words with paradigmatic gaps and words with no such gaps (e.g., Gap: *biblical* vs. NoGap: *historical*). Our findings showed that in both conditions, affixes are stripped from the root. This was evident by a similar priming effect in the Gap and NoGap conditions. Furthermore, our results demonstrated longer RTs for words in the Gap condition even though there was a similar priming effect in both conditions. We posited that the longer RTs might be attributed to the lack of a corresponding extant word for the intermediate decomposed form in the Gap condition. The longer RTs in the Gap condition were also discussed to be partially attributed to the effect of Morphological Family Size. Our findings also suggest that although the morphological decomposition in masked priming tasks is a prelexical process blind to the lexical properties of a word, word access is still sensitive to paradigmatic and lexical properties and is achieved through contact with the lexicon. Furthermore, despite the construal of affixes in paradigms with gaps as one complex morphological unit, our findings lend support for their separate decomposition.

[2] We extracted all non-compound affixed forms of the roots (i.e., both inflectional and derivational forms including prefixes and suffixes) from COCA. We did not include proper nouns or items with token frequencies less than 10 since they were mostly words with misspelling or foreign words.

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