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Does Vowel Harmony Affect Visual Word Recognition? Evidence From Finnish

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One of the most representative morpho-phonological features of Finnish is the existence of vowel harmony. Back vowels (a, o, and u) and front vowels (ä, ö, and y) cannot appear in the same monomorphemic word (e.g., PÖYTÄ [table] but not POYTÄ)—the vowels e and i are considered "neutral" and can accompany either front or back vowels (e.g., PELÄSTYÄ [get frightened]). Previous research has revealed that native speakers of Finnish use vowel harmony to help segment multilexeme compound words where each lexeme may differ in vowel harmony (e.g., työmaa = työ+maa [workplace]). In Experiments 1 and 2, we examined whether vowel harmony has an effect on the initial moments of monomorphemic word processing using the masked priming technique (lexical decision: Experiment 1; naming: Experiment 2). A target word (e.g., MÄNTY [pine]) could be preceded by a harmonious or disharmonious prime (mänty-MÄNTY vs. manty-MÄNTY; mönty-MÄNTY vs. monty-MÄNTY). As further controls, we also included a comparison with two harmonious conditions differing in the presence of a diacritical letter (mänty-MÄNTY vs. menty-MÄNTY) and a letter similarity comparison with disharmonious primes (manty-MÄNTY vs. monty-MÄNTY). To further examine whether vowel harmony has an effect at later phases of visual word processing, Experiment 3 compared the recognition of harmonious and disharmonious pseudowords in a single-presentation lexical-decision task (e.g., HÖPEÄ vs. HOPEÄ; baseword: HÄPEÄ [shame]). We found slower responses for harmonious than for disharmonious pseudowords. Taken together, these findings reveal that, while Finnish readers are sensitive to vowel harmony, this effect does not occur in the initial stages of processing.

Keywords: masked priming, word recognition, vowel harmony

A phenomenon called vowel harmony exists in several, typically agglutinative languages (e.g., Uralic languages [Finnish, Hungarian], Turkic languages [Turkish, Kazakh], among others). It refers to a morpho-phonological feature whereby all vowels in a lexeme share a phonological property (e.g., backness harmony, round harmony, height harmony, tongue root harmony, nasal harmony, or pharyngeal harmony; see Goldsmith, 1985; Rose & Walker, 2011). Here we focus on Finnish, a language that shows front-back vowel harmony.

In Finnish, front vowels (ä, ö, and y [/æ/,/ø/,/y/]) cannot appear in the same lexeme as back vowels (a, o, and u [/a/,/o/,/u/]).[1] Finnish also has two "neutral" vowels (e, i [/e/,/i/]) that can accompany either back or front vowels. For instance, the word pouta/pouta/ [dry weather] is composed of three back vowels and the word pöytä/pøytæ/ [table] is composed of three front vowels—items like poyta or pöutä that combine front and back vowels (i.e.,

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The preregistered design is accessible at https://osf.io/zj3a6
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[1] In Finnish, ä and ö are distinct letters from a and o, and they appear in Finnish dictionaries after the letter z.

vowel disharmony) could not possibly be native words in Finnish. As stated above, either front or back vowels can be combined with the neutral vowels e and i, as in pelästyä/pelæstyæ/ [get frightened] or pelastua/pelastua/ [to be saved]. Vowel harmony is a distinctive element of Finnish phonology, and native speakers have difficulty pronouncing disharmonious pseudowords like poyta or pöutä as well as loan words with no vowel harmony (e.g., olympia [Olympic] is pronounced as /olumpia/ by many Finnish speakers). Of note, other Finnic languages like Estonian have lost vowel harmony (e.g., the Estonian word täna [today] could not be a native Finnish word—the Finnish for today is tänään).

Previous studies have shown that native Finnish listeners use vowel disharmony as a word boundary cue in spoken language comprehension (Suomi et al., 1997; Vroomen et al., 1998). Using a speech segmentation task, Suomi et al. (1997) demonstrated that listeners detected better a lexeme (hymy [smile]) in a pseudoword with vowel disharmony (puhymy) than in a pseudoword with vowel harmony (pyhymy; see Vroomen et al., 1998; for a replication of this effect). Vowel disharmony provides a good cue to signal word onsets in Finnish speech. Suomi et al. (1997) also observed a stronger effect of vowel harmony for words containing front vowels (e.g., hymy) than back vowels (e.g., palo [fire]). Finally, Vroomen et al. (1998) obtained a reduced vowel harmony effect when the stress was in the first syllable of the lexeme (i.e., hy) in pseudowords like pyhymy and puhymy. In Finnish, the major stress is always at the word-initial syllable. Thus, the major stress in the second syllable of the pseudowords facilitated the detection of the lexeme and reduced the effect of vowel harmony therein.

Vowel harmony has been demonstrated to be a useful cue also in recognizing the morphological structure of multimorphemic words during reading Finnish. Although nonharmonious vowels cannot appear in single lexemes, they can appear in multilexeme compound words (as in ölj**yo**nnettomuus [oil accident]; lexeme boundary is shown in bold), marking the morpheme boundary. In an eye-tracking study, Bertram et al. (2004) showed that vowel disharmony between the two lexemes in two-constituent compound words facilitates morphological decomposition and hence the recognition of two-constituent compound words by marking the morphological boundary between the constituents. When two disharmonious vowels were adjacent to each other at the lexeme boundary (as in ölj**yo**nnettomuus), the compound word was faster to recognize during reading than when two harmonious vowels appeared at the lexeme boundary (as in ryöst**öy**ritys [robbery attempt]; lexeme boundary is shown in bold).

As the target compound words in the Bertram et al. (2004) were rather long (on average about 12 letters), readers typically made more than one fixation on the word when reading them embedded in a sentence context. Thus, Bertram et al. were able to examine the time course of the vowel harmony effect. It was absent in the first fixation made on the word, appeared in the second fixation, and was largest in the third fixation. Clearly, the study of Bertram et al. (2004) suggests that vowel harmony information may not be attained in the initial moments of word processing. However, it should be noted that the manipulated letter combination (i.e., the morpheme boundary) did not appear word-initially, but it could be as far as at the ninth and 10th letter positions when the initial lexeme was long. Thus, the Bertram et al. (2004) experiment cannot be used to disentangle whether or not vowel harmony affects the early moments of lexical processing.

In Experiments 1 and 2, we examined the extent to which vowel harmony affects the initial moments of the recognition of visually presented monomorphemic words as studied by the masked priming paradigm (Forster & Davis, 1984; see Forster, 1998, and Grainger, 2008, for reviews). In this technique, a target stimulus in uppercase is very briefly preceded by a masked prime in lowercase (around 30–50 ms); thus, allowing the researchers to manipulate prime-target relationship in various ways without the participant's awareness (e.g., form-priming: jugde-JUDGE vs. jupte-JUDGE; phonological priming: conal-CANAL vs. cinal-CANAL; translation priming: mesa-TABLE vs. luna-TABLE; semantic priming: cat-DOG vs. ink-DOG; see Grainger, 2018, for a review).

Thus, with this procedure, we can tap into early effects of vowel harmony in visual word recognition, provided that they exist (see Grainger & Ferrand, 1996; Pollatsek et al., 2005; Rastle & Brysbaert, 2006; for evidence of masked phonological priming in French, Spanish, and English). Finnish has a shallow orthography so that each letter represents a nearly perfect correspondence to a phoneme; thus, phonological decoding is quite simple (see Kujala et al., 2012; for phonological effects in Finnish; see also Seymour et al., 2003, for evidence of phonological processing among developing readers of Finnish vs. other languages). As described below, by manipulating the prime-target relationships, we created four combinations of contrasts that allowed us to examine the role of vowel harmony (via primes that contained either vowel harmony or disharmony) in the early moments of word processing. These contrasts—together with their rationale— were preregistered at Open Science Framework (OSF, https://osf.io/zj3a6).

It should be noted that the present study departs from the previous studies (Bertram et al., 2004; Suomi et al., 1997; Vroomen et al., 1998) in that we investigated whether vowel harmony as a phonological feature affects the recognition of visually presented words, whereas prior research has focused on the effects of vowel harmony on lexical segmentation. In other words, the present study is the first to examine effects of vowel harmony on visual word recognition. More generally speaking, it addresses the question of whether words' phonological features are activated early on when recognizing printed words in a transparent language with consistent grapheme-phoneme correspondences.

Before describing each contrast in Experiments 1 and 2, we should note first that the target words always contained at least one front vowel containing diacritical marks (e.g., MÄNTY [pine], PÖYTÄ [table]). The rationale was to make vowel harmony more salient: note that the vowels a and o cannot appear in the lexeme together with the vowels ä, ö, or y (e.g., poytä would be disharmonious). We chose diacritical target words (e.g., MÄNTY) over nondiacritical target words (e.g., POUTA [dry weather]), because recent research has shown greater masked priming effects from nonaccented to accented vowels than vice versa (e.g., faliz–FÁCIL is responded faster than fecil-FÁCIL [easy], but féliz-FELIZ behaves as fáliz-FELIZ [happy]; Chetail & Boursain, 2019; Perea et al., 2020; see also Kinoshita et al., 2021, for the same pattern with kana syllables). Thus, in the masked priming technique, MÄNTY-like words may be more sensitive to a manipulation of vowel harmony than POUTA-type words—also note that Suomi et al. (1997) found stronger effects of vowel harmony in speech segmentation for words with front-vowel harmony (e.g., MÄNTY) than for words with back-vowel harmony (e.g., POUTA). It should also be noted that the vowel harmony manipulation was analogous for word and pseudoword targets (i.e., the presence of diacritical marks in the prime was not indicative of lexical status of the target).

The first critical comparison was between an identity condition (e.g., mänty- MÄNTY) and a disharmonious priming condition in which a vowel with diacritical marks was replaced with its non-diacritical (disharmonious) counterpart (e.g., manty-MÄNTY). If vowel harmony does play a role in the initial moments of word processing in Finnish, one would expect slower word identification times in the disharmonious priming condition (manty-MÄNTY) than in the identity priming condition (mänty-MÄNTY). Alternatively, if the letter a in manty, which shares all its visual features with ä, activates both letter representations (i.e., a and ä) in early visual-word processing regardless of vowel harmony, one would expect similar word recognition times for manty-MÄNTY and mänty-MÄNTY. This is case in a language such as Spanish, where diacritics on a vowel signal lexical stress but not vowel quality (e.g., á-Á = a-Á; Perea et al., 2020)—note that the vowels a and á are always pronounced /a/ in Spanish (e.g., camara/'ka.ma.ra/ [camera]). Notably, the degree to which nonaccented vowels activate their accented counterparts is language-dependent. Marcet et al. (2021) showed an advantage of à-À over a-À in Catalan, a Romance language characterized by vowel reduction for unstressed vowels. In Catalan, the accented vowel à is consistently pronounced /a/, but the nonaccented vowel a can be pronounced /a/ or /ə/ (e.g., casa/'ka.sə/ [house]).

One interpretive issue with this first comparison is that, if the hypothesis of vowel harmony is supported, it is not clear whether the difference is due to the repetition of the diacritical marks or the base letter, or both. Keep in mind that, unlike Spanish or French, a and ä are considered as different letters in Finnish, each with a different sound (i.e., /a/ and /æ/). For that reason, we designed a second contrast in which we tested whether repeating the base letter across the prime and target facilitates visual word recognition. Specifically, we compared two disharmonious primes against each other, one sharing the same base letter (manty), and the other not sharing the base letter (monty) with the target word (MÄNTY). If base letter repetition facilitates visual word recognition regardless of vowel harmony, the prime manty should produce shorter word identification times for MÄNTY than its control monty. This comparison also allows us to examine effects of visual similarity in Finnish.

The third comparison examined whether the diacritical marks play a significant role in signaling vowel harmony without the need of repeating the base letter. To that end, we created a prime condition in which we replaced the base letter containing diacritical marks while keeping the diacritics (i.e., ä → ö or ö → ä; e.g., mönty for MÄNTY). If diacritical marks signal vowel harmony in the first moments of word processing, one would expect faster word identification times for mönty- MÄNTY (i.e., a harmonious pair) than for its control manty-MÄNTY (i.e., a disharmonious pair).

Finally, the fourth comparison tested whether diacritical marks play a role in signaling vowel harmony when the critical vowel is not repeated between the prime and target. To that end, we compared two harmonious priming conditions to each other, one with diacritical marks (mönty-MÄNTY) and another without (menty-MÄNTY). If the word recognition system uses the diacritical marks to signal vowel harmony in the initial moments of processing, the prime mönty should be a more effective prime than the prime menty.

In Experiment 1, we used a lexical-decision task. We chose this task because there are no mandatory phonological processes and, hence, any effects due to vowel harmony would be a better reflection of core, task-independent effects. In Experiment 2, we used a naming task, as the intrinsic phonological component in this task may boost the effects of vowel harmony. We defer an explanation of the rationale of Experiment 3 until later—this was a single-presentation lexical decision experiment directly comparing harmonious and disharmonious pseudowords.

Experiment 1 (Masked Priming Lexical Decision Task)

Method

Participants

This sample procedure and analysis plan for each of the four hypotheses was preregistered at https://osf.io/zj3a6. The participants were recruited from an introductory psychology course at the University of Turku, Finland. The participants obtained course credit for their participation. All of them were native speakers of Finnish with no reading disability or abnormal vision. In accordance with the preregistered protocol, a total of 50 participants was recruited. The rationale of this number was to obtain 1,700 observations for word trials (50 participants × 34 items/condition), which is considered sufficient for within-participants comparisons (Brysbaert & Stevens, 2018).

Materials

We selected 170 target words of 5–6 letters long in Finnish, all nouns or adjectives, from a newspaper corpus accessed by WordMill (Laine & Virtanen, 1999). The target words contained 2–3 syllables and had an average frequency of 53 occurrences per million words (range = 1–1,146 per million). All of them contained at least one diacritical vowel (i.e., ä or ö; e.g., MÄNTY, PÖYTÄ). For each target word, we created five prime conditions. The primes differed from the targets in one vowel, typically in the first syllable. The primes for the target word MÄNTY (pine) are the following: (a) identity prime (mänty); (b) repetition of the base letter without diacritical marks in the critical letter (manty); vowel disharmony, (c) different base letter + no diacritical marks (monty); vowel disharmony, (d) vowel harmony signaled by diacritical marks, but the base letter was not shared (mönty); and (e) vowel harmony but using a neutral letter (menty). We also created 170 orthographically (and phonologically) legal pseudowords to act as nonword targets by modifying consonant letters of Finnish words of the same length as the word targets (e.g., SÄPPY, SÖYNÄ). The priming conditions for the pseudoword targets were parallel to those for the word targets. Five lists of materials were created so that the target word appeared in List 1 preceded by Prime 1, in List 2 preceded by Prime 2, and so forth. Each stimulus list contained an equal number of trials for each prime condition. The presentation of the five stimulus lists was counterbalanced across the participants. Within each block, the order of trials was individually randomized. The list of the materials is available in OSF (https://osf.io/gztxa/).

Procedure

The session took place in a small experimental room. The software used to control the experiment (stimulus presentation, recording of responses) was DMDX (Forster & Forster, 2003). The stimuli were presented with a monospaced font (Courier New). We used the typical arrangement in the masked priming procedure. Each trial began by presenting a mask composed of # signs in the center of the computer screen for 500 ms—this mask had the same length as the prime/target. Then, the mask was replaced by a briefly presented lowercase prime (50 ms; five refresh cycles in a 100-Hz monitor), and the prime was subsequently replaced by the target in capital letters. The target (either a word or a pseudoword) was on the screen until the participant responded—there was also a 2-s deadline for the responses. Participants received standard lexical decision instructions in which both response time and accuracy were stressed. While the key dependent measure was the reaction time (RT), we also measured the accuracy of the responses. A short practice block preceded the experimental block. The approximate duration of the experiment was 14–16 min.

Results and Discussion

In accordance with the preregistered protocol, RTs shorter than 250 ms or greater than 3 *SD*s from the overall participants' mean were excluded from the latency analyses. The averages per condition for RTs and error rates are shown in Table 1.

(Generalized) linear mixed effects models were used to analyze the data using the lme4 package (Bates et al., 2015) in the R environment (R Development Core Team, 2020). Participants' and items' intercepts and slopes were entered as the random effects. The four planned pairwise comparisons detailed in the beginning of the article were used to test each contrast. As indicated in the preregistered protocol, inverse transformations were computed on the RTs, −1,000/RT, to reduce the skew of RT distributions, and *t* values greater than 1.96 were considered statistically significant—we also report the approximate *p* values obtained with the lmerTest package (Kuznetsova et al., 2017). The maximal model that converged was: $-1{,}000/RT \sim primetype + (1|item) + (1 + primetype|subject)$. For the accuracy data, we used generalized linear mixed effects models with the binomial distribution for correct/error responses.

While not preregistered, we also report the Bayes Factors for each comparison—these values were obtained with the BayesFactor package (Morey et al., 2015) in R using the default priors. For a comparison between Model 1 (alternative hypothesis) and Model 0 (null hypothesis), a Bayes Factor (BF_{10}) indicates how more likely Model 1 is relative to Model 0 given the data—note that $BF_{10} < 1$ would indicate evidence in favor of the null hypothesis (see Morey et al., 2016).

Latency Data

Effects of Vowel Harmony for the Primes With the Same Base Letters as the Target Word. Lexical decision times on the target word (MÄNTY) were faster in the disharmonious visually similar (manty) prime condition than in the identity (mänty) condition (585.9 vs. 595.7 ms; $b = .031$, $SE = .012$, $t = 2.691$, $p = .0091$; $BF_{10} = 6.14$).[2]

Effect of Visual Similarity for the Disharmonious Priming Conditions. Lexical decision times on the target word (MÄNTY) were faster when preceded by a visually similar disharmonious prime (manty) than when preceded by a visually dissimilar disharmonious (monty) prime (585.9 vs. 601.8 ms, respectively; $b = -.046$, $SE = .012$, $t = -3.787$, $p = .0003$; $BF_{10} = 2474.11$).

Effect of Vowel Harmony for One-Letter Vowel Replaced Conditions. There was a minimal, nonsignificant advantage of the target words (MÄNTY) when preceded by a one-letter different vowel harmonious prime (mönty) than when preceded by a one-letter different vowel disharmonious (monty) prime (596.0 vs. 601.8 ms, respectively; $b = .010$, $SE = .010$, $t = .999$, $p = .3183$; $BF_{10} = .070$).

Effect of Signaling Vowel Harmony by One-Letter Vowel Replaced Conditions. RTs on the target word (MÄNTY) were, on average, 8.8 ms faster in a fully harmonious one-letter vowel different priming condition (mönty) than in a neutral one-letter harmonious vowel different priming condition (menty; 596.0 vs. 604.2 ms, respectively; $b = -.020$, $SE = .012$, $t = -1.662$, $p = .1024$; $BF_{10} = .298$).

Accuracy Data

None of the planned comparisons approached significance.

This lexical decision experiment with the masked priming paradigm did not show any signs of an effect of vowel harmony—indeed, the Bayes Factors showed evidence of absence of this effect. Thus, these findings demonstrate that vowel harmony is not accessed early in processing in a standard word laboratory task like lexical decision. What we did find was a sizable visual similarity effect for disharmonious pairs (e.g., manty-MÄNTY faster than monty-MÄNTY), extending the findings obtained in Perea et al. (2020) in a language where accent marks have a phonological value.[3]

[2] We conducted an exploratory analysis in which we also included the participants' scores from the Author Recognition Test (ART) in English (Acheson et al., 2008) in the model of the latency data. (This was done for $N = 48$, as the data from two individuals was misplaced.) The analyses did not reveal an effect of the English ART ($p > .20$). We also conducted a parallel effect using the Finnish adaptation of the ART (Bertram & Vastamäki, 2018). In this case, we found a facilitative effect of the ART score ($t = 2.138$, $p = .038$). This effect was similar for the priming effects (all interactions: $ps > .28$).

[3] One might argue that perhaps the lack of an advantage of pöytä-PÖYTÄ (identity, harmonious) over poytä-PÖYTÄ (one-letter different, disharmonious) or of päytä-PÖYTÄ (one-letter different, harmonious) over paytä-PÖYTÄ (one-letter different, disharmonious) might have been due to some general slowdown due to the presence of a diacritical letter in the prime (ö in pöytä; ä in päytä). However, this proposal would wrongly predict an advantage of peytä-PÖYTÄ (one-letter different, harmonious) over päytä-PÖYTÄ (one-letter different, harmonious)—if anything, we found a nonsignificant advantage of päytä-PÖYTÄ.

Table 1
Mean RTs (in Milliseconds) and Accuracy for Each of the Conditions in the Masked Priming Lexical Decision Task (Experiment 1)

	Type of prime				
Words	Identity pöytä	Same base letter disharmonious poytä	Diff. base letter disharmonious paytä	Diff. base letter harmonious päytä	Diff. base letter neutral peytä
RTs	595.7	585.9	601.8	596.0	604.2
Accuracy	0.956	0.952	0.949	0.939	0.935

Note. RTs = reaction times. Mean response times and accuracy for pseudowords were very similar across conditions—they ranged between 635–640 ms and .962 and .974.

A rather unexpected result, however, is that we found an advantage of the visually similar disharmonious condition (e.g., manty-MÄNTY) over the identity (harmonious) condition (mänty-MÄNTY)—we predicted either an advantage of the identity condition or a null effect. To further inspect this effect, we obtained the density plot of the response time distributions of the two conditions. As can be seen in Figure 1, the distribution of the visually similar disharmonious condition is shifted to the left of the identity condition. This change in location (but not in shape) in the response time distributions is a common pattern in masked priming experiments, and it is typically attributed to an "encoding" advantage (see Gomez et al., 2008, for modeling evidence). We defer a discussion of this finding until the General Discussion.

The goal of Experiment 2 was to test the effects of vowel harmony with the masked priming paradigm in a word identification task with an intrinsic phonological component: the naming task.

Experiment 2 (Masked Priming Naming Task)

Method

Participants

Forty-five university students were recruited as the participants from the same pool as in Experiment 1.

Materials and Procedure

They were the same as in Experiment 1, except that only target words were used and that the participants were instructed to name aloud the target word as soon as possible while trying not to make errors.

Results and Discussion

Naming times shorter than 200 ms or greater than 3 *SD*s from the overall participants' mean were excluded from the analyses. The measurement of speech onset for each trial was obtained automatically using Chronset (Roux et al., 2017). RTs for incorrect responses and for those correct answers with hesitations (e.g., m . . . mänty) were also omitted from the analyses (.51% and .55% of the data, respectively). The average naming times in each condition are presented in Table 2. The analyses were parallel to those in Experiment 1, except that error rates (being asymptotically low) were not analyzed further.

Effects of Vowel Harmony for the Primes With the Same Base Letters as the Target Word

Naming times for the target words were identical for the identity (mänty) condition versus disharmonious visually similar (manty) prime condition (403.8 vs. 403.8 ms; $t < 1$; $BF_{10} = .043$).

Effect of Visual Similarity for the Disharmonious Priming Conditions

Naming times were faster in the visually similar disharmonious condition (manty) than in the visually dissimilar disharmonious (monty) condition (403.8 vs. 409.5 ms, respectively; $b = -3.397\text{e-}02$, $SE = 1.235\text{e-}02$, $t = -2.751$, $p = .0061$; $BF_{10} = 1.83$).

Effect of Vowel Harmony for the One-Letter Vowel Replaced Conditions

The difference in naming times for the target words between one-letter different vowel disharmonious prime (monty) and those preceded by a one-letter different vowel harmonious prime (mönty) did not approach significance (409.5 vs. 407.1 ms, respectively; $t < 1$; $BF_{10} = .0418$).

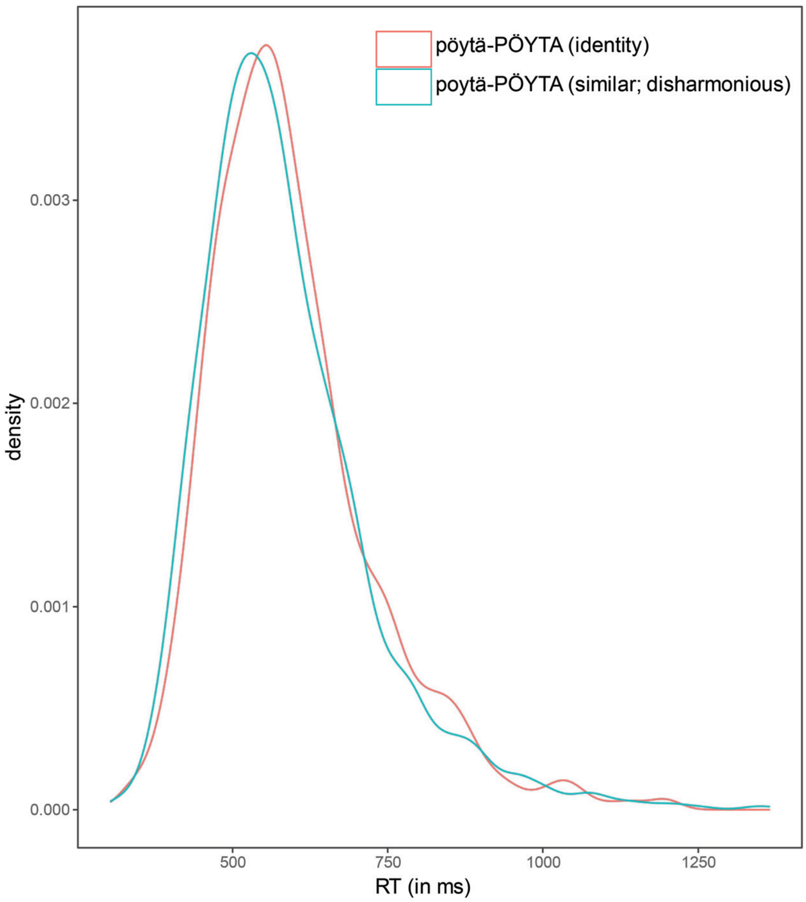
Effect of Signaling Vowel Harmony by One-Letter Vowel Replaced Conditions

The difference in naming times for the target words between one-letter different vowel harmonious prime (mönty) and those preceded by a one-letter different vowel neutral prime (menty) did not approach significance (407.1 vs. 407.7 ms, respectively; $t < 1$; $BF_{10} = .042$).

Analogously to the lexical-decision task (Experiment 1), the naming task showed a visual similarity effect for disharmonious pairs (manty-MÄNTY faster than monty-MÄNTY). More important, there were no signs of an effect of vowel harmony in a task that requires phonological processing (i.e., reading a word aloud), as deduced from the Bayes Factors. The only difference with respect to Experiment 1 was that the visually similar disharmonious condition produced remarkably similar response times as the identity condition (mänty-MÄNTY = manty-MÄNTY).[4]

[4] We also conducted an analysis adding participants' scores in the English ART (Acheson et al., 2008) in the model. We found faster responses for those individuals with higher scores in the author recognition test ($t = -2.501$, $p = .0163$). Yet, as in Experiment 1, this effect did not interact with the priming effects.

Figure 1
Density Plot of the Response Time Distributions of the Identity Condition (e.g., Pöytä-PÖYTÄ) and the Visually Similar (Disharmonious) Condition (e.g., Poytä-PÖYTÄ)



Note. See the online article for the color version of this figure.

Experiment 3 (Single-Presentation Lexical Decision Task)

Neither Experiment 1 (lexical decision) nor Experiment 2 (naming) showed any signs of an effect of vowel harmony in the early moments of printed word recognition in Finnish via masked priming. One explanation of this null effect is that vowel harmony only affects visual word processing in restricted situations, such as segmenting compound words (Bertram et al., 2004). However, a simpler hypothesis is that vowel harmony does affect printed word processing in Finnish, but its locus is not at the earliest moments of word recognition—note that the masked priming technique was devised to capture these early effects (Forster, 1998; Grainger, 2008). Indeed, in an event-related experiment in the auditory domain in Finnish, Tuomainen (2001) found an effect of vowel harmony restricted to a relatively late time window (N400). To test this premise, we directly compared the recognition of harmonious versus disharmonious pseudowords in single-presentation lexical decision with two types of pseudowords. Specifically, we created two sets of pseudowords by changing a vowel from a base word, so that they kept exactly the same consonant/vowel structure and only differed in whether the pseudoword followed vowel harmony

Table 2
Mean RTs (in Milliseconds) for Each of the Conditions in the Masked Priming Naming Task (Experiment 2)

	Type of prime				
Words	Identity *pöytä*	Same base letter disharmonious *poytä*	Diff. base letter disharmonious *paytä*	Diff. base letter Harmonious *päytä*	Diff. base letter Neutral *peytä*
RT	403.8	403.8	409.5	407.1	407.7

Note. RTs = reaction times.

(base word: VAURIO [damage in Finnish] → VÖURIO [disharmonious] or VOURIO [harmonious]; baseword: HÄPEÄ [shame in Finnish] → HOPEÄ [disharmonious] or HÖPEÄ [harmonious]). Note that, while a behavioral single-presentation lexical-decision task with harmonious versus disharmonious pseudowords cannot be used to determine the exact locus of the effect (early vs. late), it does test whether there are processing differences depending on vowel harmony (see Perea & Lupker, 2004, for a rationale of this task as a complement of masked priming).

If vowel harmony has an effect during printed word recognition in Finnish, one would expect faster "no" responses to disharmonious pseudowords than to harmonious pseudowords. Alternatively, if vowel harmony is only used to help solve ambiguities when reading long multimorphemic words in Finnish, the two conditions would behave similarly. In addition, this experiment also serves to test whether there are any asymmetries in vowel harmony effects for pseudowords created from back-vowel basewords (e.g., VOURIO vs. VÖURIO [baseword: VAURIO]) and front-vowels basewords (e.g., HÖPEÄ vs. HOPEÄ [baseword: HÄPEÄ]), as suggested by Suomi et al. (1997).

Method

Participants

We recruited 28 university students from the same pool as in Experiments 1 and 2. This resulted in a similar number of observations per condition as in Experiments 1 and 2 (28 participants × 60 items/condition: 1,680 observations).

Materials

We selected 120 Finnish words of 5–6 letters (mean length: 5.5 letters; mean word-frequency per million: 83.7) to act as base words. Half of words had back vowel harmony (e.g., VAURIO [damage]) and the other half had front vowel harmony (e.g., HÄPEÄ [shame]). For each word, we created: (a) a harmonious pseudoword by replacing a front/back vowel with a harmonious vowel (e.g., VAURIO → VOURIO; HÄPEÄ → HÖPEÄ); and (b) a disharmonious pseudoword by replacing a front vowel with a back vowel (or a back vowel with a front vowel; e.g., VAURIO → VÖURIO; HÄPEÄ → HOPEÄ). Each pseudoword was presented in one of two counterbalanced lists, so that all participants were presented with 60 harmonious and 60 disharmonious pseudowords (e.g., VOURIO would be presented in List 1 and VÖURIO would be presented in List 2). For the purposes of acting as "word" stimuli in the lexical-decision task, we selected an additional set of 120 Finnish words of 5–6 letters long (mean length: 5.5 letters; mean word-frequency per million: 54.1)—half of the words showed back-vowel harmony (e.g., JUHLA) and the other half showed front-vowel harmony (e.g., SÄRKY).

Table 3
Mean Response Times (in Milliseconds) and Accuracy for Each of the Conditions in the Single-Presentation Lexical Decision Task (Experiment 3)

Measure	Words	Pseudowords	
		Harmonious	Disharmonious
RTs	641.4	748.8	694.6
Accuracy	0.967	0.951	0.979

Note. RTs = reaction times.

Procedure

The procedure was similar to that of Experiment 1, except that there were no primes and each stimulus item was preceded by a 500-ms fixation point (+).

Results and Discussion

Incorrect responses and RTs less than 250 ms were removed from the analyses. Table 3 displays the mean RTs and accuracy per condition in the experiments. As in Experiments 1 and 2, we used (generalized) linear mixed-effects models to analyze the data. For the pseudoword data, the fixed factor was vowel harmony (harmonious vs. disharmonious). The maximal models that converged were: for the latency data, −1,000/RT ∼ target_type + (1 + target_type | item) + (1+ target_type | subject); for the accuracy data: accuracy ∼ target_type + (1 + target_type | item) + (1 | subject). We also report the Bayes Factors for the latency data.

Results showed faster responses to disharmonious than harmonious pseudowords, $b = .089$, $SE = .015$, $t = 54.021$, $p < .001$; $BF_{10} = 2.06e + 15$). The analyses on the accuracy data were in the same direction (i.e., disharmonious pseudowords yielded better accuracy), but the effect of vowel harmony was not significant, $b = -.515$, $SE = .461$, $t = -1.119$, $p = .263$.

Thus, the present experiment showed faster responses to disharmonious pseudowords than to harmonious pseudowords. It demonstrates that native Finnish readers are sensitive to vowel harmony when processing relatively short items.

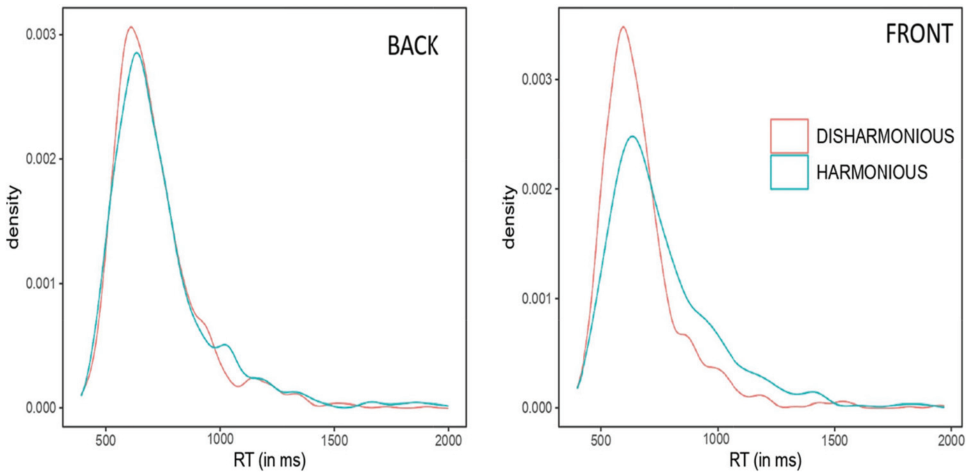
A remaining issue is whether there are asymmetries in the effects of vowel harmony in the recognition of pseudowords created from a front or a back harmonious set. As indicated in the Introduction, when detecting words in continuous speech, Suomi et al. (1997) found stronger effects of vowel harmony for words with front vowels (e.g., detecting hymy in the sequence pyhymy vs. puhymy) than for words with back vowels (e.g., detecting palo in the sequence kupalo vs. kypalo).

To examine whether this pattern also extends to the visual modality, we conducted a post hoc analysis including type of baseword (front harmony [HÄPEÄ] vs. back harmony [VAURIO]) as a second fixed factor in the design. Results showed that the effect of vowel harmony was substantially greater for those pseudowords with a baseword containing front-vowel harmony (harmonious pseudowords: 760 ms and 6.2% of errors; disharmonious pseudowords: 674 ms and 1.1% of errors) than for those pseudowords with a baseword containing back-vowel harmony (harmonious pseudowords: 738 ms and 3.7% of errors; disharmonious pseudowords: 716 ms and 3.1% of errors). The statistical analyses showed a strong interaction between the two factors ($p < .001$ for both latency and accuracy analyses; see Figure 2 for the density plot of the response time distributions).

The asymmetrical effect of vowel harmony in the present experiment generalizes to the visual modality the findings reported by Suomi et al. (1997) in continuous speech. One explanation for this asymmetric pattern is that vowel harmony effects are reliant on letter/phoneme frequency (see Suomi et al., 1997, for a similar point): back vowels are much more frequent in Finnish than front

Figure 2

Density Plot of the Response Time Distributions of Harmonious and Disharmonious Pseudowords Created From Basewords With Back-Vowel Harmony (Left Panel) and With Front-Vowel Harmony (Right Panel)



Note. See the online article for the color version of this figure.

vowels (a [12.2%], o [5.6%], u [5.0%] vs. ä [3.6%], ö [.4%], y [1.7%]; Practical Cryptography, 2017). Indeed, word frequency tends to be higher for back-harmony words than for front-harmony words (the average baseword frequency in the experiment were 128 vs. 40 occurrences per million)—note, however, that the effect of the baseword frequency on one-letter different pseudowords are minimal in lexical decision (e.g., see Perea et al., 2005).

The stronger effects of vowel harmony for pseudowords with front-vowel harmony rules out an interpretation suggesting that participants merely evaluated the legality of the pseudowords—this hypothesis would have predicted a strong effect of vowel harmony for pseudowords created from both front-vowel and back-vowel harmony. Of note, a number of loan words have not adapted to the vowel harmony rules of Finnish (e.g., olympia, parfyymi, dynastia, etc.), so Finnish readers often encounter disharmonious words.

General Discussion

We conducted three experiments to test the role of vowel harmony during printed word recognition in Finnish. In Experiments 1 and 2, we used Forster and Davis' (1984) masked priming technique to tap into the first moments of visual word processing. Results revealed no signs of an effect of vowel harmony in either lexical decision or naming when using one-vowel different primes with diacritical marks (the disharmonious pair manty-MÄNTY behaved as the harmonious pair mänty-MÄNTY) or one-vowel different unmarked (neutral) vowels (the harmonious, unmarked harmonious pair menty-MÄNTY behaved as the marked harmonious pair mönty-MÄNTY). This null effect of vowel harmony does not mean that participants were not processing the primes: we found a visual similarity effect for one-vowel different harmonious primes in both lexical decision and naming experiments (manty-MÄNTY faster than monty-MÄNTY); thus, extending recent research (Marcet & Perea, 2017; Perea et al., 2020, 2021). In Experiment 3, we used a single-presentation paradigm that compared the recognition of harmonious and disharmonious pseudowords. Results revealed faster and more accurate responses to disharmonious pseudowords (e.g., HYÖNÄ [baseword: HÄPEÄ]) than to harmonious pseudowords (e.g., HÖPEÄ)—this effect was greater for front harmony than back harmony words, as in the study of Suomi et al. (1997) with continuous speech. In sum, the present experiments demonstrate that vowel harmony information is not encoded (or used) early in visual word processing—as evidenced by two masked priming experiments, but it helps decide whether a visually presented item is a Finnish word or not—as evidenced by Experiment 3.

The lack of an effect of vowel harmony in the masked priming technique (Experiments 1 and 2) combined with the presence of an effect of vowel harmony in the single-presentation technique (Experiment 3) suggests that the locus of the effect manifests during relatively late stages of the word recognition process. This interpretation is consistent with the findings Bertram et al. (2004) obtained in a sentence reading task, in which the effects of vowel harmony for reading compound target words did not occur during the initial fixation made on the word. While the effect of vowel harmony was sizable in the second fixation, it reached its maximum in the third fixation. Taken together, these findings suggest that information regarding vowel harmony in Finnish does not play a role in early visual word processing. In other words, phonological features of words across syllable boundaries—in terms of vowel harmony—do not become active in the initial stages of word recognition, at least to the extent that they could affect the recognition process.

Before accepting the hypothesis of a null early effect of vowel harmony during word processing, it may be important to consider one additional possibility. One could argue that vowel harmony effects could be more salient for PÖYTÄ-type words (i.e., with a noticeable disharmony for primes like poytä given the diacritics in ä) than for MÄNTY-type words (for which a prime like manty might be less salient). Post hoc analyses of the two masked priming experiments showed that the pattern of priming effects was very similar for the two types of items—note that 133 of 170 words were PÖYTÄ-type of words. This further supports the hypothesis that vowel harmony information is not used in the initial moments of word identification.

The current findings are also consistent with the absence of an effect of tonal information using a masked priming paradigm—also both in lexical decision and naming—in a tonal language with an orthographic writing system like Thai. Specifically, Winskel and Perea (2014) found faster responses for pairs sharing the initial consonant (but not tonal information) like หอง- หอง [room] /hĐ:ŋ1/-/hĐ:ŋ2/ than for the control ศอง– หอง /sĐ:ŋ1/-/hĐ:ŋ2/ as well as similar response times for pairs varying in the initial consonant but sharing the tone realization (e.g., ศอง– หอง /sĐ:ŋ2/-/hĐ:ŋ2/) and their controls with a different tone realization (e.g., ศอง– หอง/ sĐ:ŋ1-/hĐ:ŋ2/). Winskel and Perea concluded that, in Thai, “access to (phonological) tone information during the process of visual-word recognition occurs relatively late—or at least that tone information is used relatively late” (p. 218). We believe that a parallel conclusion may apply with respect to vowel harmony in Finnish.

There is one surprising finding obtained in the lexical-decision task that deserves some comments—we would like to stress, though, that this issue is only tangential to the main conclusions of this article. We found in Experiment 1 an advantage of pairs like manty-MÄNTY (i.e., a disharmonious condition) over mänty-MÄNTY (i.e., the identity condition). The analyses of the response time distributions reflect a shift in the response time distributions, so the effect appears to be stable (see Figure 1). This finding clearly suggests that a nondiacritical vowel “a” can also activate its diacritical variant ä in the first moments of word processing. A null effect would have been consistent with recent evidence in Spanish in which facil-FÁCIL is as effective as the identity pair fácil-FÁCIL. It should be noted, however, that in Spanish á and a are the same letter (pronounced as /a/), whereas in Finnish a/ä and o/ö are different letters that not only have a distinct pronunciation, but also a diverging vowel harmony. The unexpected finding was the disadvantage of the (harmonious) identity condition. Together with the implication that prime-target vowel harmony does not play a role during the first moments of word processing in Finnish, the advantage of manty-MÄNTY over mänty-MÄNTY suggests that the diacritical letter ä in mänty slowed down recognition of the target word. This makes sense given the facts that: (a) in Finnish, as in other languages, diacritical letters are much less frequent than nondiacritical letters (e.g., a = 12.2%; o = 5.6%; ä = 3.6%; ö = .4%; Practical Cryptography, 2017; see New & Grainger, 2011, for evidence of letter frequency effects); and (b) diacritical letters are visually more complex than their nondiacritical counterparts. Although this reasoning is admittedly ad hoc, there is a recent lexical decision experiment with the masked priming paradigm showing exactly this same pattern. In Spanish, Marcet et al. (2020) found faster response times in a visually similar one-letter different condition (muneca-MUÑECA [doll]) than in the identity condition (muñeca-MUÑECA)—the diacritical letter ñ is less frequent than the letter n (.3% vs. 6.7%, respectively; Practical Cryptography, 2017) and it is also visually more complex. Importantly, the advantage of manty-MÄNTY over mänty-MÄNTY vanished in a task that requires phonological processing (i.e., naming task), which suggests that this effect is orthographic in nature.

Critically, the effect of vowel harmony with short stimuli (5–6 letters) in a single-presentation lexical-decision task (Experiment 3) strongly suggests that participants encode information on front/back vowel harmony at some stage during printed word recognition: RTs were slower for harmonious than for disharmonious pseudowords. Of note, this difference occurred to a much larger degree for pseudowords whose basewords contained front vowels (e.g., HÖPEÄ vs. HOPEÄ [baseword: HÄPEÄ]) than for pseudowords whose basewords contained back vowels (e.g., VOURIO vs. VÖURIO [baseword: VAURIO]; see Figure 2). We prefer not to speculate as for the underlying reasons for this asymmetry other than indicating that the same pattern also occurs during the detection of words during continuous speech (Suomi et al., 1997). Instead, we believe that this issue can be better answered by using a technique that directly tracks the time course of information processing (e.g., recording the event-related potentials during word recognition).

At a more general level of theorizing, the present experiments in the visual modality on vowel harmony in Finnish share some remarkable similarities to previous studies in the auditory modality. In the auditory modality, Tuomainen (2001) found an effect of vowel harmony in auditory segmentation using event-related potentials in a 400–500 ms time window, which suggests a late processing stage for this information. In the present experiments in the visual modality, we found an effect of vowel harmony effect when using a single-presentation task, but not in masked priming. Thus, the pattern of effects in both modalities suggests that the effects of vowel harmony occur at relatively late stages of word recognition.

An avenue for further research is to examine in detail the emergence of vowel harmony. In a picture naming task, Leiwo et al. (2006) found that Finnish children as young as 2–3 years old followed vowel harmony when naming the pictures. Notably, the few errors tended to be with the (less frequent) front-class vowels (e.g., in the word pöytä, which contains three front vowels). As indicated above, this is in line with adult data: a front/back vowel asymmetry has been reported with adult individuals in both the auditory and visual modalities. To obtain experimental evidence for the emergence of symmetric/asymmetric patterns of vowel harmony, one option is to manipulate the frequency of front versus back vowels using an artificial grammar-learning paradigm and recruiting adult speakers of a language without vowel harmony. Note that participants can acquire vowel harmony in a single training session of 10–20 min (see Finley, 2017, for a review).

To sum up, we designed three experiments to study the role of vowel harmony information in recognizing printed words in Finnish. In both masked priming experiments (lexical decision and naming), we found evidence against the hypothesis that vowel harmony facilitates early word processing. Finnish readers do encode (and use) vowel harmony information at a later processing stage, as we obtained clear evidence of an effect of vowel harmony when participants had to decide whether a letter string was a Finnish word or not (e.g., HÖPEÄ [harmonious pseudoword] produced longer “no” responses than HOPEÄ [disharmonious pseudoword]). Future research should examine the role of morpho-phonological features such as vowel harmony during word processing in sensory modalities that rely on serial input, such as reading

Finnish compound words in braille (see Fischer-Baum & Englebretson, 2016, for morphological effects in braille) or during spoken word recognition (e.g., using variants of the gating or visual world paradigms; e.g., Shen et al., 2021).

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