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The distinctive role of vowel harmony in visual word recognition: The case of Turkish

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Abstract
Vowel harmony is a phenomenon in which the vowels in a word share some features (e.g., frontness vs. backness). It occurs in several families of languages (e.g., Turkic and Finno-Ugric languages) and serves as an effective segmenting cue in continuous speech and when reading compound words. The present study examined whether vowel harmony also plays a role in visual word recognition. We chose Turkish, a language with four front and four back vowels in which approximately 75% of words are harmonious. If vowel harmony contributes to the formation of coherent phonological codes during lexical access, harmonious words will reach a stable orthographic-phonological state more rapidly than disharmonious words. To test this hypothesis, in Experiment 1, we selected two types of monomorphemic Turkish words: harmonious (containing only front vowels or back vowels) and disharmonious (containing front and back vowels)—a parallel manipulation was applied to the pseudowords. Results showed faster lexical decisions for harmonious than disharmonious words, whereas vowel harmony did not affect pseudowords. In Experiment 2, where all words were harmonious, we found a small but reliable advantage for disharmonious over harmonious pseudowords. These findings suggest that vowel harmony helps the formation of stable phonological codes in Turkish words, but it does not play a key role in pseudoword rejection.

Keywords
Vowel harmony; lexical decision; orthography; lexical access

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Vowel harmony is a phenomenon in which vowels within a word share certain phonetic features (e.g., frontness vs. backness harmony, roundness harmony, among others). This phenomenon is present in several families of languages (e.g., Turkic Languages like Turkish and Kazakh; Finno-Ugric Languages like Finnish and Hungarian, among others; see Goldsmith, 1990; Rose & Walker, 2011, for reviews). In these languages, the vowels that constitute a word require similar mouth and lip movements, potentially facilitating speech production (Khalilzadeh, 2010) and speech segmentation (Ketrez, 2013). Furthermore, vowel harmony also affects morphological processes (e.g., suffixes sharing the vowel harmony with the root) and word formation (van der Hulst, 2016).

An open question of theoretical interest is whether vowel harmony, a phonological phenomenon, also affects word recognition in the visual modality. In the present paper, we examine this issue in Turkish, which uses a transparent orthography. In Turkish, there are four front vowels (i, ö, ü, e; pronounced as /i/, /ø/, /y/, and /e/, respectively) and four back vowels (ı, o, u, a, pronounced as /ɯ/, /o/, /u/, and /a/, respectively). In harmonious words, when the initial syllable of a word begins with a front vowel, the following syllables should only contain front vowels (e.g.,

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güven [trust], *ödül* [award]). Conversely, when the first syllable starts with a back vowel, the subsequent syllables should only contain back vowels (e.g., *karar* [decision], *yakın* [near]). While all words in old Turkic were harmonious, the evolution of the Turkic languages, together with the influence of other cultures and languages across time (e.g., Arabic, Persian, and, more recently, Western languages), has reduced the proportion of harmonic words (Bıyıklı, 2020; Harrison et al., 2002). Nonetheless, modern Turkish still displays a well-defined pattern of vowel harmony: around 75% of the words follow this principle (Harrison et al., 2002). Of note, other Turkic languages (e.g., Modern Uzbek; Harrison et al., 2002), as well as some languages from other families (e.g., standard Estonian; Kiparsky & Pakusalu, 2003; Korean: Sohn, 2001), have essentially lost vowel harmony. Before introducing the rationale of the experiments, we briefly review the literature that has examined the role of vowel harmony in the auditory and visual domains.

In the auditory domain, it has been shown that infants can rapidly pick up vowel harmony patterns by segmenting the syllables into proto-words in a sequence of continuous speech (i.e., vowel harmony provides a salient cue for word segmentation) (e.g., Altan et al., 2016, for evidence in Turkish). Critically, this pattern occurs even with infants that have never been exposed to a language with vowel harmony (e.g., English; see Mintz et al., 2018). Vowel harmony also plays a role in child-directed speech; for instance, Ketrez (2013) examined a corpus-based study that compared two harmonious languages (Turkish and Hungarian) to two non-harmonious languages (Polish and Persian). In the two harmonious languages, within-word sequences in child-directed speech were more likely to be harmonious than disharmonious, suggesting that languages with vowel harmony provide learners with extra cues for word segmentation during continuous speech (i.e., sequences with a different pattern of vowel harmony would be treated as separate words). Vowel harmony is also a helpful segmentation cue for adult speakers. Suomi et al. (1997) asked adult Finnish participants to identify target trisyllabic nonsense words (e.g., *hymy* /ˈ*hymy*/) embedded within spoken sequences such as *pyhymy* /ˈ*pyhymy*/ (harmonious string) and *puhymy* /ˈ*puhymy*/ (disharmonious string; /*u*/ is a back vowel and /*y*/ is a front vowel). Accuracy was higher, and response times were faster when the targets occurred in disharmonious than harmonious strings (see also Vroomen et al., 1998, for similar evidence), revealing a role for vowel disharmony in Finnish as a segmentation cue in speech (see Kabak et al., 2010, for similar results in Turkish).

Vowel harmony also plays a role in the visual domain. In an eye movement study during sentence reading in Finnish, Bertram et al. (2004) included two types of compound words: the constituents could share the same vowel harmony (e.g., *satu**olento*** [fairytale creature] bold emphasis is for illustrative purposes to signal the two constituents, both with back vowels in the example), or not (e.g., *sähkö**asentaja*** [electricity expert]; front vowel harmony in the first constituent and back vowel harmony in the second).[1] Bertram et al. (2004) found shorter gaze durations on harmonically dissonant compound words, suggesting that a lack of vowel harmony across the constituents would help segment compound words. Recently, Perea et al. (2022; Experiment 3) examined whether vowel harmony could modulate lexical processing in Finnish using monomorphemic words using a lexical decision task. As vowel disharmony only occurs in a minimal subset of loan words in Finnish, Perea et al. (2022) only manipulated vowel harmony for pseudowords. Specifically, they compared harmonious pseudowords (e.g., *höpeä*) and disharmonious pseudowords (i.e., containing both front and back vowels, *vöurio*). They found faster and more accurate "nonword" responses to disharmonious than to harmonious pseudowords and suggested that vowel disharmony would make the items less wordlike. One limitation of their experiment is that, because of the characteristics of Finnish words, their manipulation of vowel harmony only involved pseudowords (i.e., all words were harmonious). To reach firm conclusions on the role of vowel harmony during visual word recognition, it is necessary to compare harmonious and disharmonious words in a language that, while showing vowel harmony, also has a non-negligible number of disharmonious words. Turkish is an ideal language because around one in four words are disharmonious, thus allowing us to select well-matched sets of harmonious and disharmonious words.

The main goal of the present study was to examine the impact of vowel harmony on lexical access in visually presented Turkish words. To that end, we employed the most common task in visual word recognition, lexical decision (see Balota et al., 2007; Dufau et al., 2012). It has been hypothesised that visual word recognition involves the integration of various codes, including orthographic and phonological codes (e.g., phonological coherence hypothesis; see Frost, 1998; Van Orden & Goldinger, 1994). In the context of a lexical decision task, it has been suggested that orthographic and phonological codes from the visual stimuli would combine into a single measure of *coherence* (Van Orden & Goldinger, 1994). The amount of coherence can be translated into a parameter of quality of evidence in mathematical models of lexical decision (e.g., diffusion model; Gomez, 2012; Ratcliff et al., 2004). The higher the degree of coherence elicited by the orthographic and phonological codes of a printed word, the higher the values of quality of evidence for a "word" response. Under the assumption that a phonological constraint such as vowel harmony contributes to the formation of coherent phonological codes (see Berent et al., 2001, for evidence of phonological constraints in lexical decision experiments), harmonious words would reach a higher level of coherence than disharmonious words (see Van Orden & Goldinger, 1994, for a similar reasoning with English irregular words).

In Experiment 1, we selected two types of monomorphemic Turkish words: harmonious (i.e., containing only front or back vowels; e.g., *temel* [basis] front and *orman* [forest] back) and disharmonious (i.e., containing both front and back vowels; *kalem* [pen] or *vakit* [time]) matched in word frequency and orthographic neighbourhood. The predictions are clear. If vowel harmony reflects the internalisation of phonological rules in the mental lexicon of Turkish speakers, the phonological codes of the words following vowel harmony will resonate more as "words" than those from the words that do not follow this principle. In this scenario, we expect faster word identification times for harmonious than disharmonious words. Alternatively, if vowel harmony does not serve as a marker for word recognition in Turkish, given that non-negligible proportion of disharmonious Turkish words (around one of four), one would expect similar response times and error rates for harmonious and disharmonious words. For comparison purposes, we employed the same manipulation for the set of pseudoword foils (i.e., pseudowords could be harmonious or disharmonious). While the predictions for pseudowords in the lexical decisions are less precise (see Dufau et al., 2012, for a discussion on the mechanisms for "nonword" decisions), one could argue that disharmonious pseudowords would resonate less than harmonious pseudowords. If so, one would expect faster "nonword" responses (or more errors) for disharmonious than harmonious pseudowords—note that this pattern would replicate the experiment of Finnish conducted by Perea et al. (2022; Experiment 3). As Experiment 2 was designed after knowing the findings of the initial experiment, we prefer to introduce its rationale later.

Experiment 1

Method

The sampling, method, procedure, and analysis strategy were pre-registered at https://osf.io/ep3gx.

Participants. Thirty-six native speakers of Turkish took part in the experiment (9 women, M_{age} = 26.9 years, SD_{age} = 7.72)—this yields 2,556 observations per condition, which is above the criteria suggested by Brysbaert and Stevens (2018) for small-sized effects. They were recruited from online settings (via social networks) and had normal/corrected vision. None of them reported having any speech/reading problems. All participants were recruited in Turkey and were either university students or had a university degree. They signed an informed consent form prior to the experimental session. Both experiments were approved by the Experimental Research Committee of the University of Valencia.

Materials. We selected 142 Turkish nouns of 4 to 6 letters (M = 4.97, SD = 0.81) from WordLex (blog corpus; Gimenes & New, 2015). Half of these nouns were harmonious (all vowels were from the same type, front or back, for instance, *sanat* [art]). They had an average frequency of 135.84 occurrences per million words ($Mean_{Zipf}$ = 4.941, SD_{Zipf} = 0.413) and a mean OLD20 distance of 1.604 (SD_{OLD20} = 0.284). The other half of words were disharmonious (i.e., words contained both front and back vowels, for instance, *zafer* [victory]), with an average frequency of 112.66 occurrences per million words ($Mean_{Zipf}$ = 4.845, SD_{Zipf} = 0.416) a mean OLD20 value of 1.654 (SD_{OLD20} = 0.257). Both sets of words were matched in word frequency and orthographic neighbourhood (both ps > .25). The manipulation for the nonwords was the same (harmonious pseudowords vs. disharmonious pseudowords). 142 pseudowords of 4 to 6 letters (M = 4.97, SD = 0.81) were generated via Wuggy (Keuleers & Brysbaert, 2010) using the plug-in for Turkish developed by Erten et al. (2014). Half of the pseudowords were harmonious (M_{OLD20} = 1.785, SD_{OLD20} = 0.205), and the other half were disharmonious (M_{OLD20} = 1.835, SD_{OLD20} = 0.321) (p > .25). The set of stimuli is presented in the OSF link.

Procedure. The experiment was implemented with PsychoPy (Peirce et al., 2019) in the Pavlovia experiment platform (https://www/pavlovia.org; Open Science Tools, Nottingham, UK). We used the typical lexical decision task procedure. Participants were asked to decide, as rapidly as possible while being reasonably accurate, whether the letter string was a meaningful word by pressing "M" (word) or "Z" (nonword). Before the experiment, there was a brief practice session consisting of 16 trials. Each trial began with a fixation cross with 500 ms. While participants had unlimited time to respond in practice rounds, in experimental trials, after the presentation of the target (either word/pseudoword with harmony/disharmony), they had 2 s to respond. Every 120 trials, participants were asked to take a short break before continuing the experiment.

Data analysis. The inferential analyses used Bayesian linear mixed-effects models with the *brms* (Bürkner, 2017) package in RStudio (R Core Team, 2022). Separate analyses were carried out for words and nonwords. In both cases, the only fixed factor was the type of stimulus (harmonious vs. disharmonious), and the random-effect structure was the maximal allowed by the design (i.e., random intercepts and slopes of Type of stimulus for subjects and random intercepts of Type of stimulus for items). The ex-Gaussian family was utilised to model reaction time, and the Bernoulli family was employed for the binary accuracy data. The model involved four chains and 10,000 iterations (the warm-up phase consisted of 2,000 iterations). Based on the posterior distribution of each parameter, we present the 95% Bayesian Credible Intervals. If 0 is outside of the 95% CrI for the coefficient corresponding to the type of stimulus, then we will consider that there is credible evidence for an effect of vowel harmony.

Table 1. Means and standard errors (in parentheses) of reaction time and accuracy for word conditions and vowel harmony conditions in Experiment 1.

	Response time	*Accuracy*
Word		
Harmonious	604 (3.2)	0.974 (0.003)
Disharmonious	623 (3.3)	0.973 (0.003)
Pseudoword		
Harmonious	685 (3.5)	0.946 (0.004)
Disharmonious	686 (3.6)	0.943 (0.005)

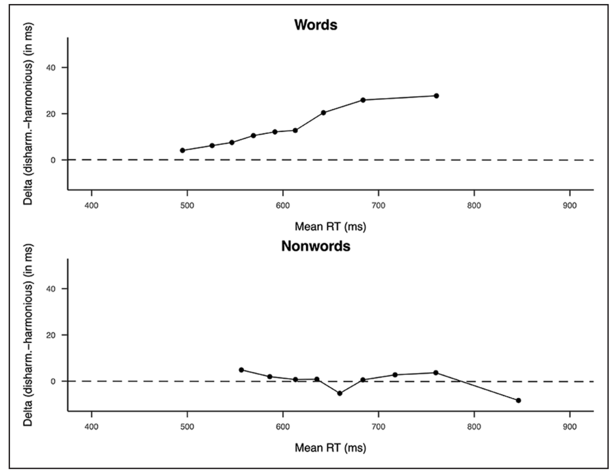

Figure 1. Delta plots (differences between disharmonious and harmonious conditions across the .1, .2, . . ., .9 quantiles) for words (top panel) and pseudowords (bottom panel) in Experiment 1.

Results and discussion

Reaction times shorter than 250 ms were removed from the latency data (0.06% of trials). A response deadline of 2,000 ms was set, and the programme automatically classified any response exceeding this timeframe as an error (0.33% of trials). No participants' accuracy fell below the pre-registered threshold of 75%. Table 1 presents the mean response times and accuracy for both words and nonwords as a function of vowel harmony.

Words

Word identification times were faster for harmonious than disharmonious words (b = 10.36, 95% CrI [2.79, 17.87]). We found no evidence of a vowel harmony effect in the accuracy data (b = −0.27, 95% CrI [−0.92, 0.33]).

Pseudowords

Both response time data and accuracy data were similar for disharmonious pseudowords and harmonious pseudowords (response times: b = 0.79, 95% CrI [−8.80, 10.35], accuracy: b = −0.13, 95% CrI [−0.66, 0.42]).

Following the preregistration protocol, we also conducted exploratory data analyses (Tukey, 1977) that examined the dynamics of the effect of vowel harmony over time via delta plots (De Jong et al., 1994). The logic was that, for words, a measure of coherence in a lexical decision task could be interpreted as quality of evidence in a diffusion model (drift-rate parameter; Ratcliff et al., 2004; Van Orden & Goldinger, 1994). In this scenario, the response time distribution of harmonious words would be less skewed (due to the diffusion model's geometry) than the disharmonious word's response time distribution. If so, the effect of vowel harmony for words should increase across quantiles, as also happens with variables like word frequency (see Ratcliff et al., 2004). To examine this question, we computed the reaction times for nine quantiles (.1, .2, .3, . . ., .9) per participant and condition. Then, we averaged these reaction times across participants to obtain "vincentiles" for each quantile, we computed the difference (disharmonious—harmonious) across quantiles for those vincentilized response times. We then plotted these points, with the reaction times on the x-axis and the deltas on the y-axis. As an illustration, a flat line around 20 ms would indicate a shift in reaction time distributions—typically signalling a difference in headstart processing, whereas an ascending trend across quantiles would suggest differences in the quality of evidence rates across conditions (see Fernández-López et al., 2021; Gomez et al., 2013).

For words, the delta plot in the left panel of Figure 1 reflects an increasingly larger effect in the higher quantiles. This pattern is consistent with the idea that vowel harmony affects the quality of information during lexical decision (see Gomez et al., 2013). For nonwords, the delta plot was flat and approximately centred RT around zero, indicating that the mean and distributional shapes are quite similar in the two conditions being compared.

In sum, readers can identify faster harmonious than disharmonious words in Turkish, revealing that this vowel harmony affects lexical access. While the critical finding in this experiment corresponds to the lexical items (i.e., the words), we believe that it is relevant to examine the potential reasons for the apparent discrepancy between the lack of an effect of vowel harmony for pseudowords in the present experiment and the experiment reported by Perea et al.'s (2022) in Finnish. There were two basic differences. On one hand, the set of words in the Finnish experiment was always harmonious. Thus, the lack of vowel harmony in Finnish would have signalled that the stimulus was not a word, leading to faster and more accurate "nonword" responses to disharmonious pseudowords. On the other hand, in Turkish, around 25% of words are not harmonious, whereas in Finnish, disharmonious words are extremely scarce. Thus, unlike Finnish readers, Turkish readers may not use "vowel disharmony" as a reliable marker for "nonword" responses.

Table 2. Means and standard errors (in parentheses) of reaction time and accuracy for pseudowords and vowel harmony conditions in Experiment 2.

	Response Time	*Accuracy*
Pseudoword		
Harmonious	658 (3.51)	0.950 (0.004)
Disharmonious	652 (3.58)	0.957 (0.004)

For Words: mean RT: 581 ms, standard error; 2.22, Accuracy: 0.955.

To tell apart these two explanations, we designed Experiment 2. As in Perea et al.'s (2022) Experiment 3, all words were harmonious. The set of pseudowords was the same (i.e., the difference was that all words were now harmonious). If the cause of the discrepancy between the vowel harmony effect for pseudowords between the current experiment and Perea et al.'s (2022) Experiment 3 were only the experimental design, one would expect an effect of vowel harmony for pseudowords when only using harmonious words in the set of stimuli. Alternatively, if vowel disharmony is not a marker for "nonword" responses in Turkish, one would expect similar response times and error rates for harmonious and disharmonious pseudowords.

Experiment 2

Method

All methodological elements of Experiment 2 were preregistered at https://osf.io/25wsh.

Participants. A new sample of 36 Turkish participants from the same population as Experiment 1 participated in the experiment (19 women, M_{age}=26.94, SD_{age}=8.74).

Materials. We employed the same set of pseudowords as in Experiment 1. As for the word stimuli, we kept the 71 harmonious nouns from Experiment 1 and replaced the disharmonious nouns with other harmonious nouns of similar word frequency from the same corpus—the whole list is available at the OSF link. Overall, the mean frequency of the words in Experiment 1 and 2 were similar ($Zipf_{exp1}$=4.845, $Zipf_{exp2}$=4.906, t=0.302, p > .30).

Procedure and data analysis. They were the same as in Experiment 1.

Results and discussion

Reaction times shorter than 250 ms were disregarded (1.27% of trials). Error responses were removed from the latency analysis (5.25% of trials). There were no participants whose accuracy fell below the threshold of 75%. Table 2 provides the descriptive statistics associated with response times and accuracy for the nonwords within the two vowel harmony conditions.

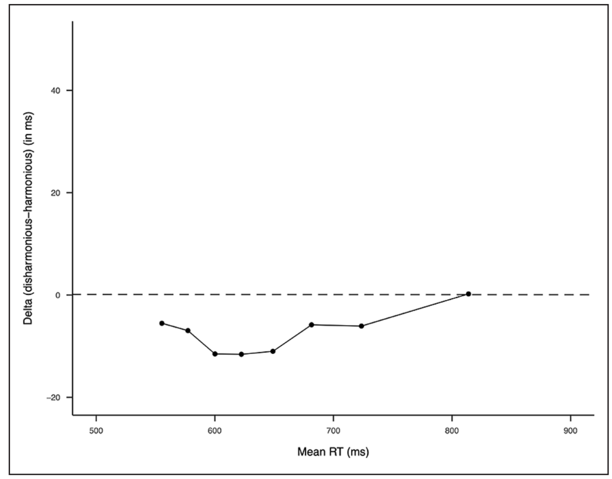

Figure 2. Delta plot (differences between disharmonious and harmonious conditions in the .1, .2, . . ., .9 quantiles) for pseudowords in Experiment 2.

The analyses of the latency data showed evidence of faster responses (around 6 ms, on average) for disharmonious pseudowords than harmonious pseudowords (b=−9.06, 95% CrI [−17.73, −0.35]). Accuracy showed the same trend as the response times (i.e., responses to disharmonious pseudowords were 0.7% more accurate than for harmonious pseudowords), but the 95% credible interval crossed zero (b=0.19, 95% CrI [−0.22, 0.60]).

Delta plots

Similar to Experiment 1, we obtained the delta plot for the pseudowords. As can be seen in Figure 2, response times were slightly faster for disharmonious words across quantiles. When we compare Figure 2 to the Pseudoword Panel of Figure 1, it is evident that vowel harmony can be used by Turkish readers to reject the pseudowords. This occurred when we made all the words harmonious, indicating that the use of harmony has some contextual component (possibly even strategic within the experiment).

In summary, we observed a vowel harmony effect on pseudowords in the same direction as the Finnish experiment (Perea et al., 2022). However, the magnitude of the effect was dramatically smaller than in the parallel experiment in Finnish (749 vs. 695 ms for harmonious and disharmonious pseudowords, respectively; Perea et al., 2022). As we indicated in the Introduction, vowel disharmony is extremely infrequent for Finnish words, so it can be considered a reliable marker for "nonword" responses in the lexical decision task. The scenario is quite different for Turkish readers, for whom vowel disharmony is not a salient marker for "nonword" responses—one out of four words is disharmonious.

General discussion

For several families of languages (e.g., Turkish [Turkic languages], Finnish [Finno-Ugric languages], among others), vowels in a monomorphemic word share either front vowels or back vowels (i.e., backness-frontness vowel harmony). Previous research has consistently demonstrated that vowel harmony facilitates word segmentation in auditory and visual modalities (Bertram et al., 2004; Suomi et al., 1997; Vroomen et al., 1998). The present study examines whether vowel harmony influences visual word recognition processes in monomorphemic words.

We chose Turkish as the target language because, while it exhibits vowel harmony, it also contains a non-negligible proportion of disharmonious words (around one of four words; Harrison et al., 2002). We hypothesised that if vowel harmony contributes to the formation of more coherent orthographic-phonological codes during lexical access, harmonious words (e.g., *temel* [basis], containing two front vowels) would lead to a higher degree of coherence than disharmonious words (e.g., *kalem* [pen], containing a back vowel and a front vowel). This would result in faster "word" responses in lexical decision tasks than disharmonious words. Results from Experiment 1 effectively showed faster response times for harmonious than disharmonious words (see Table 1 and top panel of Figure 1). Notably, vowel harmony only had minimal impact on pseudowords, suggesting that the absence of vowel harmony in Turkish does not significantly signal "nonword" responses in the lexical decision task—note that the small effect of vowel harmony on pseudowords was only observed in Experiment 2, where the word stimuli consisted solely of harmonious words (see Figure 2).

The presence of faster lexical decision responses to harmonious than disharmonious words aligns well with the global coherence hypothesis (Frost, 1998; Van Orden, 1987; Van Orden & Goldinger, 1994). In this framework, the more coherent the phonological codes, the higher the quality of information driving the lexical decision responses. Another similar proposal is Ratcliff's (1978) diffusion model; this model uses the metaphor of resonance between a probe and mental representation. Assuming that "word" responses are driven by a measure of match between the visual input and the lexical entries in memory that reflect the quality of evidence (Ratcliff et al., 2004), harmonious words would elicit a greater degree of match than disharmonious words. Notably, in this type of model, the predictions apply not only to the mean response times but also to the distribution of the response times. Specifically, the response time distribution of the words with a higher resonance/coherence (i.e., harmonious words) would be less skewed than those with lower resonance/coherence. This is precisely the pattern we found for word stimuli in Experiment 1 (see Figure 1). The effect of vowel harmony increased across quantiles, reflecting a more skewed distribution for the disharmonious pseudowords. This finding suggests that harmonious words in Turkish produce a higher quality of evidence—presumably due to more coherent phonological codes—than disharmonious words. Thus, vowel harmony appears to affect the degree of "wordness" in lexical decisions. An exploratory analysis using the diffusion model (Ratcliff, 1978; Ratcliff et al., 2004, 2016) with the D*M package (Van den Bergh et al., 2020) confirmed this pattern: drift rates (a parameter that reflects the quality of evidence) were higher for harmonious than for disharmonious words (see the online Supplementary Material). Further research with other Turkic languages that have a higher or lower percentage of harmonious words than Turkish (e.g., Turkmen [83.0%] versus Uzbek [53.8%], Harrison et al., 2002) may help delineate the role of vowel harmony during lexical access in this family of languages.

The effect of vowel harmony was minimal or null for pseudowords—we only found a minimal 6 ms advantage for disharmonious than harmonious pseudowords in Experiment 2, when all words were harmonious. Although this latter pattern was expected by the global coherence hypothesis (i.e., vowel disharmony would signal a "no" response to a larger degree than vowel harmony), the effect was much smaller than a parallel experiment in Finnish (Perea et al., 2022)—note that unlike Turkish, vowel disharmony in monomorphemic Finnish words only occurs in an extremely reduced set of loan words. The dissociation of the effects of vowel harmony for words and pseudowords in lexical decision favours the idea that "no" responses in the lexical decision task may be driven by a variety of mechanisms (see Dufau et al., 2012), and they may not reflect the same mechanisms for "word" and "nonword" responses.

In sum, our findings align with those models that assume that orthographic and phonological codes are integrated during lexical access (e.g., see Ratcliff et al., 2004; Stone & Van Orden, 1994): harmonious words are identified more rapidly than disharmonious words in a task that does not have an overt phonological component (lexical decision), suggesting a complex interplay between orthographic and phonological processes. Further studies should investigate the impact of vowel harmony using techniques that rely on time dynamics, such as the recording of event-related potentials (Grainger & Holcomb, 2009). Finally, it is important to run experiments using more ecological settings than word laboratory tasks, such as registering the readers' eye movements when reading sentences containing a target word that could be harmonious or disharmonious (see Rayner et al., 2012).

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Data Accessibility Statement

The sampling, method, procedure, and analysis strategy were preregistered at https://osf.io/ep3gx (Experiment 1) and https://osf.io/25wsh (Experiment 2). The scripts, data, output, and stimuli are available at: https://osf.io/ue9ts/

Supplementary Material

The Supplementary Material is available at: qjep.sagepub.com

Note

1. In Finnish, there are three front vowels (ä /æ/, ö /ø/, and y /y/) and three back vowels (a /a/, o /o/, and u /u/) together with the two neutral letters that can accompany either front or back vowels (e /e/, i /i/).

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