Vowel harmony is a phonological phenomenon in which vowels within a word should share certain phonetic features (e.g., frontness vs. backness harmony, roundness harmony, among others). It is present in several families of languages (e.g., Turkic Languages [e.g., Turkish, Kazakh], Finno-Ugric Languages [e.g., Finnish, Hungarian], Korean, Japanese; Goldsmith, 1990; Rose & Walker, 2011). This phenomenon also affects morphological processes and word formation, thus being a critical component of the language's phonology.

In the auditory domain, previous research has shown that vowel harmony can serve as a marker of word segmentation. Ketrez (2013) examined child-directed speech in a corpus-based study that compared to non-harmonious languages (Polish and Persian) with to harmonious languages (Turkish and Hungarian). They found that within a word in harmonious languages, sequences were more likely to be harmonious than disharmonious, thus harmonious languages provide learners with extra cues for word segmentation. In Suomi et al.'s (1997) study involving Finnish speakers, participants were asked to identify target trisyllabic nonsense words (e.g., *hymy /ˈhymy/*) embedded within strings such as *pyhymy /ˈpyhymy/* (harmonic string) and *puhymy /ˈpuhymy/* (disharmonic string; *u* is a back vowel and *y* is a front vowel). Listeners showed higher accuracy and faster responses to identify targets in disharmonious strings than in harmonious ones. Thus, that means vowel harmony provides a segmentation cue. In addition, Kabak et al. (2010) compared French and Turkish speakers to investigate the effect of vowel harmony on word segmentation. Unlike the Suomi et al study, participants were asked to detect the non-word targets presented in written form (e.g., *paVO*) inside of the 5-syllable nonsense spelling letter combinations (harmoniously matched [*goLUshopaVO*] or mismatched [*gøLYshøpaVO*]). It was observed that when the target and syllable are mismatched harmoniously, Turkish speakers demonstrate more accurate detection. Unlike French speakers, Turkish speakers were more sensitive to vowel sequences in word segmentation.

The present research investigates vowel harmony during visual word recognition in Turkish. In Turkish, there are four front vowels (i, ö, ü, e; [/i/, /ø/, /y/, /e/, respectively]) and four back vowels (ı, o, u, a [/ɯ/,/o/,/u/,/a/, respectively]). When the initial syllable of a word begins with a front vowel, the following syllables should align with other front vowels (e.g., *güven* [trust] and *ödül* [award]). Conversely, when the first syllable starts with a back vowel, the subsequent syllables should also have back vowels (e.g., *karar* [decision] and *yakın* [near]). Before introducing the experiments, we first review the relatively scarce literature on front/back vowel harmony during sentence and word recognition.

Furthermore, there is empirical evidence showing that vowel harmony during reading can be used to segment compound words in Finish (Bertram et al., 2004). They investigate short and long compound words while monitoring eye movements in Finish. Shorter gaze duration on harmonious compound words suggests that vowel harmony facilitates the segmentation of compound words. The logic is that if the initial part of a word contains front vowels and the final part contains back vowels, the two parts must correspond to different morphemes. Recently, Perea et al (2021) examined whether vowel harmony also applies to individual items in a Finnish in lexical decision experiment. As disharmonious words are extremely infrequent in Finnish and occur in a small subset of loan words, they only focused on the pseudowords—indeed, Finnish speakers have difficulty pronouncing the word (olympia [Olympic], /ˈolymp(ː)iɑ-/) and they often normalize it to /ˈolimp(ː)iɑ-/. Their logic was that disharmonious pseudowords in Finnish could be considered less wordlike than harmonious pseudowords. Perea et al. (2021) found faster and more accurate responses to disharmonious pseudowords than harmonious pseudowords, thus suggesting that Finnish readers are sensitive to vowel harmony during lexical access.

Notably, the languages with vowel harmony vary in terms of the proportion of words that follow this principle. In languages like Finnish, vowel disharmony in monomorphemic words only occurs in an extremely reduced set of loan words (e.g., olympia [Olympic]), thus making it unfeasible to test the role of vowel harmony during visual word recognition. Fortunately, the scenario is quite different in Turkic languages. While all words in old Turkic were harmonious (VIII century; Harrison et al., 2002), the influence of other cultures across time has reduced this percentage. At the beginning of the XXI century, the estimation is that less than half of the Turkish lexicon in the Exampled Great Turkish Dictionary (2005) comes originally from Old Turkic (around 32%), whereas there are large percentages of words in which the origin was Arabic (39%), Persian (12%), and Western languages (17%) (Bıyıklı, 2020). Nonetheless, we should note that modern Turkish still displays a well-defined vowel harmony pattern: around 75% of the words follow this principle (see Harrison et al., 2002).

In the present study, we designed two experiments that examined the impact of vowel harmony on visual word recognition in Turkish. As in the Perea et al. (2021) experiments, we employed a lexical decision task, which is the most usual task in the literature on word recognition. In Experiment 1, we selected two types of monomorphemic words, harmonious (i.e., containing only front vowels or back vowels) and disharmonious (i.e., containing both front and back vowels). If vowel harmony reflects the internalization of phonological rules in the mental lexicon of Turkish speakers, words adhering to vowel harmony rules are processed faster or more accurately than those that do not. This hypothesis aligns with the theory of phonological encoding, suggesting that phonologically regular words are easier to retrieve and recognize due to their consistency with the phonological rules stored in a speaker's linguistic knowledge. For comparison purposes, we employed the same manipulation for the set of pseudoword foils (i.e., pseudowords could be harmonious or disharmonious). In this case, the predictions are less clear, although following the logic of Perea et al. (2020), if vowel harmony is taken as a marker for wordlikeness, one would expect faster response times (or more errors) for disharmonious pseudowords (i.e., pseudowords that do not follow the typical vowel harmony pattern) than for harmonious pseudowords. As Experiment 2 was designed after knowing the findings of the initial experiment, we prefer to introduce its rationale later.

**Experiment 1**

**Method**

*Participants*

This sample procedure and analysis were pre-registered at <https://osf.io/ep3gx>. Thirty-six native speakers of Turkish participants took part in the experiment (M = 26.89 years, SD = 7.72). The participants were recruited from online settings and they had normal/corrected vision. None of them reported having any speech/reading problems.

*Materials*

We selected 142 nouns of 4 to 6 letters (M = 4.97) from an online blog corpus in Turkish [WordLex, (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, OLD20 = 1.604). The other half of words were disharmonious (ı.e., words contained both front and back vowels, for instance, ZAFER [victory]), with an average frequency of 112,66 occurrences per million words (Zipf = 4.845, OLD20 = 1.654). The manipulation for the target nonwords was the same (harmonious pseudowords vs disharmonious pseudowords). These pseudowords were generated via Wuggy (Wuggy, Keuleers & Brysbaert, 2010).

*Procedure*

The experiment was implemented by PsychoPy (Peirce et al., 2019) and Pavlovia.org (Open Science Tools, Nottingham, UK) was used as the platform of the experiment. The typical lexical decision task procedure was followed. Participants were asked to determine if the string was a meaningful word or not. There was a brief practice session before the experiment, consisting of 16 trials. Each trial began with a fixation cross with 500ms. 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 seconds to respond. Every 120 trials, participants were asked to take a short break before continuing the experiment.

*Data analysis*

The data was analyzed using a Bayesian linear mixed model, with separate analyses carried out for word and non-word goals. In the case of word targets, the only fixed factor considered was the type of word (harmonious vs. disharmonious). The exgaussian family was utilized to model reaction time, while the Bernoulli family was employed for accuracy data. The analyses for the pseudoword targets will be the same for the word targets. The model implementations involved the use of 4 chains and 10,000 iterations (with a warm-up phase of 2000 iterations).

**Results and Discussion**

Reaction times shorter than 250 ms were disregarded (N = 7, 0.06%). A response deadline of 2000 ms was set, and any response exceeding this timeframe was automatically classified as an error by the program (N = 37, 0.33%). There were no participants whose accuracy fell below the pre-registered threshold of 75%.

Table X provides the descriptive statistics associated with response times and accuracy for both words and nonwords within the vowel harmony conditions.

|  |  |  |  |
| --- | --- | --- | --- |
| **Table x.** Means and standard deviations (inside of the brackets) of reaction time and accuracy for word conditions and vowel harmony conditions. | | | |
|  |  | *RT* | *Accuracy* |
| *Word* | |  |  |
|  | Harmonious | 604.28 (160.3) | 0.97 (0.16) |
|  | Disharmonious | 623.24 (169.2) | 0.97 (0.16) |
| *Pseudoword* | |  |  |
|  | Harmonious | 684.59 (169.8) | 0.95 (0.23) |
|  | Disharmonious | 686.46 (175.1) | 0.94 (0.23) |

*Words*

The reaction times were, on average, 19 ms faster for harmonious than disharmonious words (*b* = 10.36, 95% CrI [2.79, 17.87]). We found no evidence of a vowel harmony effect for the accuracy data (*b* = -0.27, 95% CrI [-0.92, 0.33]).

*Pseudowords*

The reaction times were similar for disharmonious pseudowords and harmonious pseudowords (effect; 2 ms, *b* = 0.79, 95% CrI [-8.80, 10.35]). The accuracy rate was equal for harmonious pseudowords and disharmonious pseudowords (effect; 1%, *b* = -0.13, 95% CrI [-0.66, 0.42]).

In Experiment 1, we focused on exploring the impact of vowel harmony on word recognition in the Turkish language. As we hypothesized, readers were faster in recognizing harmonious words than disharmonious words, thus constraining the models of visual word recognition when applied to Turkish. However, unlike the Finnish lexical decision experiment conducted by Perea et al. (2022), there were no signs of a parallel effect of vowel harmony for pseudowords in Turkish.

**Experiment 2**

In Experiment 2, the goal was to examine whether it is possible to find a vowel harmony effect for pseudowords in Turkish. There are two reasons for the discrepancies between the findings in Finnish and Turkish regarding vowel harmony for pseudowords:

On the one hand, in the Perea et al. (2022) study, all words were harmonious (disharmony would not be natural for Finnish, and these items are typically loan words for which Finnish speakers may tend to normalize the pronunciations), whereas for the pseudowords, half were harmonious, and half was disharmonious. Thus, a lack of harmony would signal that the stimulus was not a word. In Experiment 1, half of the pseudowords were harmonious, half was disharmonious, and half of the words were harmonious, and half was disharmonious; therefore, the lack of vowel harmony in the setup of the Experiment 1 was not a marker of “lexicality” and this could be an explanation for the lack of an effect of vowel harmony for pseudowords in the experiment.

On the other hand, one might argue that vowel harmony in Turkish is not particularly salient. Keep in mind that some Turkish words are not harmonious (and this is not the case in Finnish). Indeed, the effect of vowel harmony in Turkish in Experiment 1 was relatively small. Thus, all other things being equal, Turkish readers may not use “vowel disharmony” as a cue to classify an item as a pseudoword. In this scenario, one would not expect an effect of vowel harmony for pseudowords in the lexical decision task.

**Method**

*Participants*

This sample procedure and analysis were pre-registered at <https://osf.io/25wsh> Thirty-six Turkish participants took part in the experiment (M = 26.19, SD = 7.82). The participants were recruited from online settings and all of them were native speakers of Turkish. None of them reported having any speech/reading problems.

*Materials*

The harmonious nouns utilized in Experiment 1 were maintained, and disharmonious nouns were replaced with new harmonious nouns from the same corpus. This adjustment was made to ensure that there is no significant difference between the Zipf of all Turkish words in Experiment 1 and Experiment 2 (Zipfexp1 = 4.845, Zipfexp2 = 4.906, *t* = 0.302). The same pseudowords in Experiment 1 were used in Experiment 2.

*Procedure*

The procedure is the same as Experiment 1.

*Data analysis*

Reaction times shorter than 250 ms were disregarded (*N =*  435, %4.5). A response deadline of 2000 ms was set, and any response exceeding this timeframe was automatically classified as an error by the program. There were no participants whose accuracy fell below the threshold of %75.

The data analysis method is the same as Experiment 1.

*Results*

Error responses and response times (RTs) lower than 250 ms were removed from the latency and accuracy analyses *(N =*  435, %4.5). Table X provides the descriptive statistics associated with response times and accuracy for both words and nonwords within the vowel harmony conditions.

|  |  |  |  |
| --- | --- | --- | --- |
| **Table x.** Means and standard deviations (inside of the brackets) of reaction time and accuracy for word conditions and vowel harmony conditions. | | | |
|  |  | *RT* | *Accuracy* |
| *Word* | |  |  |
|  | Harmonious | 585.10 (159.9) | 0.97 (0.18) |
| *Pseudoword* | |  |  |
|  | Harmonious | 668.20 (181.6) | 0.95 (0.23) |
|  | Disharmonious | 664.00 (187.9) | 0.96 (0.21) |

The reaction times were slightly faster for disharmonious pseudowords compared to harmonious pseudowords (effect; 4.20 ms, *b* = -8.18, 95% CrI [-17.26, 0.84]), However, since the credible interval contains 0, we can conclude no evidence against this difference. The accuracy rate was the same for disharmonious pseudowords compared to harmonious pseudowords (effect; 0.1, *b* = 0.14, 95% CrI [-0.13, 0.13]).

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Similarly, Arik (2015) attached harmonious and disharmonious suffixes to pseudowords (e.g,., *vüğde* and *vüğda*, harmonious and disharmonious respectively) and examined the acceptability rate with 7-point Likert scale. The study revealed that pseudowords with harmoniousally structured suffixes were preferred more than disharmoniousally structured ones.