Speech Prosody 2024
2-5 July 2024, Leiden, The Netherlands

How pupillary responses reflect the predictability of word stress in Turkish?

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Abstract

Processing of word stress is a complex mechanism that has an impact on prosodic information, the predictability of speakers' native language, and their sensitivity to shifting stress positions. It is still unclear whether the complexity arises in response to alternations in Turkish stress patterns and whether they exhibit sensitivity to syllable structure. To address these questions, two studies were designed to focus on the pupil dilation response (PDR), a measure employed as a proxy for cognitive load. The current study examined the changes in pupil size with forty-six native Turkish speakers. In Experiment 1, 30 CV.CV.CV words were used with canonical final stress and 30 words in a 2×3 design with penultimate stress pronounced with final, medial, and initial stress types each. In Experiment 2, a syllable weight factor was added by using 30 CVC.CV.CV words in a 3×3 design from each of the three stress types with shifts to other syllables. The LME models showed that the changes from exceptional stress to a default final position do not directly cause increased PDR for Experiment 1. However, the results for Experiment 2 suggest that syllable weight is sensitive to PDR and plays a significant role in cognitive processing.

Index Terms: stress, perception, pupil dilation, syllable structure, Turkish

1. Introduction

Turkish exhibits consistent word stress patterns with the final syllable of a prosodic word being predictably stressed (e.g., *nafaka* [na.fa.ká], 'alimony'). However, there are exceptions to this pattern, with some words having emphasis on the penultimate syllable (e.g., *parola* [pa.ró.la], 'password') or the antepenultimate syllable (e.g., *karyola* [ká.rjo.la], 'bedstead'). Prior studies have demonstrated that the misplacement of stress leads to challenges in the processing of stress [2, 7, 27]. It is not yet clear whether these difficulties are a result of changes in all Turkish stress patterns or whether syllable structure has an impact on them [16, 17, 18, 19, 20, 30]. The investigation of word stress is a complex procedure that has influenced prosodic information regarding the ability of speakers to predict stress positions during the retrieval of words in their native language. This has been investigated through several behavioral investigations.

This present study aims to investigate (i) whether Turkish speakers have difficulty judging stress shifts in their native language for different stress violations and (ii) whether pupil dilation is sensitive to the processing of stress predictability. To this end, two online pupillometry experiments, including different syllable structures, were conducted using pupillometry during auditory processing. The pupil dilation response (PDR) gives us cognitive information about how Turkish word stress interacts with neurolinguistic and psycholinguistic models of stress processing. This shows that the predictability of stress may affect the processing of stress information.

2. Theoretical background

2.1. Word Stress in Turkish

Turkish has two distinct prosodic levels of word stress. The syllables in a lexical construction determine the first degree of stress, which is word stress [18, 19, 30]. Turkish is a stress-accent language, meaning that words are by default emphasized on their final syllable [15, 16, 17, 18, 19, 20, 30]. Regardless of the quantity of suffixes, stress frequently occurs on the last syllable of morphologically intricate compositions. Turkish employs non-final stress in addition to the default word-final stress pattern. Secondly, the presence of stress in irregularly stressed words in Turkish [18, 19, 30] can be linked to either a syllable that carries word stress or to the utilization of a root that carries word stress, such as the roots referred to as Sezer's roots [30]. He noted that place name roots in Turkish are accentuated on the initial syllable when the medial syllable position is unstressed (e.g., *Çánkırı* [çan.kı.rı]). Word stress appears on the penultimate syllable (e.g., *Antálya* [an.tal.ya]); however, the penultimate syllable is accentuated, while the antepenultimate is heavy (e.g., *Kastámonu* [kas.ta.mo.nu]).

The irregular stress pattern in Turkish is also quantity-insensitive; vowel length does not show stressed syllables, and morphophonological elements have a role, specifically in the form of prestressing suffixes [16, 17, 18]. In regular co-phonology [16], there are two levels of place names formed through derivational processes. The first level consists of place names created with suffixes that explicitly indicate a place, such as [-istan] (e.g., *Yunan-istán*) [17]. The next level includes place names formed with more general suffixes like [-mAz], which are likely converted into place names through a process of non-stressing zero derivation [16, 17]. Additionally, concerning word stems, any deviations from the final stress form in Turkish can be accounted for by the predetermined trochaic foot. For instance, while Sezer roots have penultimate stress, a trochaic foot is generally placed at the end of the stem (*Amásya* [a.mas.ya]). On the other hand, if a word has a stressed syllable that is light and comes before a stressed syllable that is heavy, the stress pattern of the word shifts one syllable to the left, causing the stress to fall on the antepenultimate syllable (e.g., *Mánisa* [ma.ni.sa]) [16, 17, 19, 30]. There exists research [16, 18] that brings about different solutions to foot structure approaches. They address regular and irregular stress patterns in Turkish by defining the phonological word domain. According to this well-designed approach, the stress pattern in the phonological word falls on the last syllable, which includes the root and most suffixes.

10.21437/SpeechProsody.2024-228

2.2. Processing of Stress Perception

The predictability of stress positions has a significant impact on both the capacity to recognize changes in stress and the capacity to comprehend stress patterns [7, 10, 11, 13, 28]. Dupoux, Peperkamp, and their colleagues conducted a series of processing studies [11, 12, 13, 14, 27, 28] to examine how participants use predictable stress patterns to contribute to stress information during language processing. Their research with participants who generally speak French demonstrated inadequate proficiency that necessitates the comprehension of stress information at a conceptual level. To demonstrate the need for stress abstraction, Dupoux and colleagues' experiments ask participants to recall a series of pseudowords with various stress patterns that they have previously heard. Researchers contend that participants who speak a language with consistent stress patterns do not need to retain stress information in their phonological representation, which can lead to challenges in remembering stress distinctions at a later stage. So, they come up with a type of stress called "deafness" [27], which says that newborns categorically perceive the difference between (non-)default stress as soon as they learn how to recognize stressed syllable patterns in their language.

The majority of relevant studies [2, 7, 8, 9, 10, 21, 25] that looked into the neural correlates and incremental processing of stress perception focused on processing prosody rather than lexical access related to stress. Although there have not been any PDR studies specifically looking into these issues in the Turkish language yet, research on other languages and event-related potentials (ERPs) results from a few Turkish studies [10, 35] help to understand the neurological mechanisms involved in perceiving stress. For instance, Domahs and colleagues [10] investigated the predictability of stress patterns in the Turkish language by using ERPs. They used monomorphemic trisyllabic words that have stress on either the final syllable or the medial syllable. Their results from ERPs for stress violations on the final stress words elicited an N400; however, violations on the non-final stress words elicited a P300. They conclude that stress predictability does not uniformly contribute to "stress deafness" in stress processing. Instead, it only occurs for the default stress pattern in Turkish. Another relevant processing study is the study of Zora and colleagues [35]. They examined the cognitive processing of acoustic cues such as spectral intensity, duration, and f0 in stress perception by using ERP in Turkish. They concluded that the use of spectral tilt, rather than intensity, was employed to represent the influence of loudness more accurately on stress perception.

3. Methods

3.1. Speakers

Forty-six speakers (32F, M_{age}=23.06; 14M, M_{age}=22.71) took part in the pupillometry experiments. All speakers were native and monolingual speakers of Turkish with normal or corrected-to-normal vision and no neurological, hearing, visual, or language impairments. They were the same speakers in both experiments. Ethical approval for this study was granted by the Ethical Board Committee of the University (Approval Number: İ5-191-19). A written consent form and instructions were provided in Turkish to speakers before the experiments.

3.2. Stimuli

Two pupillometry experiments were conducted with trisyllabic Turkish common words. The stimuli were sampled from the Turkish National Corpus [1] and the spoken language dictionary of Turkish [13]. These were the stimuli in Experiment 1. There were 30 CV.CV.CV words with a canonical final (e.g., *nafaka* [na.fa.ká], 'alimony') and 30 penultimate stress words (e.g., *parola* [pa.ró.la], 'password') pronounced with initial, medial, and final stress in a 2×3 pattern. To do Experiment 2, 30 CVC.CV.CV words from final (e.g., *leblebi* [leb.le.bí], 'roasted chickpea'), penultimate (e.g., *daktilo* [dak.tí.lo], 'typewriter'), and antepenultimate (e.g., *karyola* [ká.rjo.la]) stress types were used, with stress shifting to each pronounced with initial, medial, and final stress with a 3×3 design. A syllable weight factor was added to the first syllable in Experiment 2. 90 CV.CV.CV type filler words were added as place names for both experiments. The stimuli were recorded in a sound-proof booth in the Phonetics Laboratory of Ankara University, Brain Research Center. For the acoustic characterization of the stimuli, Praat [6] program was used to stress perception manipulation. The acoustic stimuli were analyzed in *ProsodyPro* package [34] under Praat according to their mean f0, duration, and mean intensity values for each target syllable. To confirm pitch manipulations, Linear Mixed-effects Models (LMMs) were used in R [29] with a 2×3 design for Experiment 1 and a 3×3 design for Experiment 2 (AcousticMeasure ~ WordType * StressPosition + Acceptability + (1|Item)) after model comparisons based on the Akaike Information Criteria (AIC).

3.3. Apparatus and Procedure

Pupil diameters were measured using the EyeLink 1000+ eye-tracker at a 250 Hz sampling rate and SR Research Experiment Builder Software [31] in Linguistic Laboratory of Ankara University. Before the data acquisition, practice experiments and a nine-dot calibration were conducted to ensure adequate gaze measurements. The left and right pupils were recorded during the experiments. The laboratory was soft-lighted, and all speakers were seated in front of a flat 22-inch LED monitor with 1920×1080 pixels. To reduce the motion artifacts and improve the calibration accuracy, speakers' heads were stabilized using a chin rest placed 60 cm from the presentation screen. During the experiments, the stimuli were presented binaurally through the headphones in a randomized order. When the pupillometry recording was enabled, a black fixation dot (Arial, 26 font size) was in the center of a gray screen (R:106, G:106, B:106). After the practice sessions, a nine-dot calibration and validation procedure were performed. If the validation indicated that the spatial accuracy had deteriorated to less than ±1°, then the eye tracker was recalibrated. The same procedure with the same speakers was used in both experiments. Each trial was preceded by a 700 ms baseline period and followed by a 1300 ms post-stimulus offset. Speakers were asked to focus on the fixation cross to avoid artifacts and eye blinking and to listen to target words presented in carrier sentences such as in the example of ([Kadın *daktilo* dedi] > [The woman *typewriter* say-past]). Speakers were not informed of the main purpose of both experiments. They were instructed to give yes-or-no responses by pressing the left (correct) and right (incorrect) buttons if the word they heard was a place name or not. Experiments were conducted biweekly. Experiment 1 lasted

approximately 40 minutes, while Experiment 2 extended to 60 minutes, including calibration, validation, practice, and breaks.

3.4. Preprocessing and Data Analysis

The data preprocessing involved utilizing the raw baseline pupil from recordings of the right eye. Preprocessing was carried out using the *PupilPre* 0.6.2 package [23] in R [29]. First, the raw pupil data were smoothed using a Hanning filter. Before and after the missing data points, 100 milliseconds (ms) of the signal were eliminated based on the methodology. Subsequently, the missing data were interpolated using a cubic spline fit [32]. Trials with more than 15% missing values were excluded from the subsequent analysis. The baseline pupil size for each trial was identified by averaging the pupil size in the time window spanning from 200 ms before the stimulus onset, and then standard baseline subtraction was performed for each trial [5, 26]. In the final step, the pupil data were downsampled to 50 Hz. Blinks and artifacts from more than 30% of the trial were excluded from the analysis. For the analysis of the time window following the stimulus onset, the data were baselined using a window extending from 200 ms before the onset to 3000 ms after the post-stimulus offset.

The statistical analyses were performed using R [29] with the following packages: *lme4* [4], *ggplot2* [33], and *lmerTest* [22]. Random intercepts were initially incorporated into an empty model as ITEM and SPEAKER following [3]. Subsequently, fixed factors (i.e., WORD TYPE, STRESS POSITION) were added, along with the inclusion of random slopes for predictors (i.e., (1 + WordType * StressPosition | Speaker)). The WORD TYPE factor included two levels (penultimate and final) in Experiment 1, three levels (antepenultimate, penultimate, and final) in Experiment 2, and STRESS POSITION included three levels (initial, medial, and final stress). The comparison of differences in least-squares mean and confidence intervals for fixed factors in the models was conducted across experiments. Post-hoc pairwise comparisons were also executed using the *lsmeans* package [24] in R. For the conclusive LMMs, the model included two-way interaction terms among fixed factors with two random factors after model comparisons: Pupil ~ WordType * StressPosition + (1+WordType * StressPosition | Speaker) + (1 | Item). To conduct a thorough comparison of stress positions, the specific model is applied separately to each word type: Pupil ~ StressPosition + (1+StressPosition | Speaker) + (1 | Item).

4. Results

4.1. Experiment 1: PDR for exceptional and default stress positions

Figure 1 shows the changes in pupil dilation across time windows (in milliseconds) in Experiment 1: initial, medial, and final stress positions with final and penultimate word types. LMMs analysis revealed significant main effects for the STRESS POSITION between final and medial ($\beta = 28.03$, SE = 11.44, z = 2.45, $p < 0.01$) and final and initial ($\beta = 23.90$, SE = 11.74, z = 1.98, $p < 0.05$) stressed words. However, there is no significant main effect for the WORD TYPE between final and penultimate ($\beta = 2.88$, SE = 10.62, z = 0.27, $p = 0.78$), as expected. The interaction of WORD TYPE and STRESS POSITION was significant for medial stress words ($\beta = -29.55$, SE = 13.20, z = −2.23, $p < 0.03$) but not significant for initial ($\beta = -17.94$, SE = 13.10, z = −1.37, $p = 0.17$) stressed words.

Pairwise comparisons for the canonical final STRESS POSITION on final word type between final and initial ($\beta = -23.28$, SE = 11.73, z = −1.98, $p < 0.05$), and final and medial ($\beta = -28.03$, SE = 11.44, z = −2.45, $p < 0.01$) stress positions indicated significantly high performances for pupillary responses to stress. On the other hand, the pairwise comparisons for canonical medial stress position for penultimate WORD TYPE between medial and initial ($\beta = -6.81$, SE = 12.25, z = −0.55, $p = 0.57$), and medial and final ($\beta = 1.52$, SE = 9.69, z = 0.15, $p = 0.87$) stress positions were not significant, as expected.

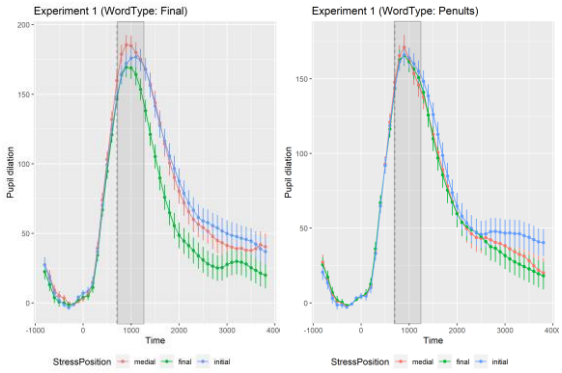


Figure 1: *Pupil dilation across time in Experiment 1.*

4.2. Experiment 2: PDR for syllable weight effect

In Experiment 2, Figure 2 shows how the pupils changed during different time windows (in milliseconds) for initial, medial, and final stress positions with final, penultimate, and antepenultimate word types according to the syllable weight effect at the initial stress position in Turkish. In the LMMs, there were no main effects that were significant for the STRESS POSITION. There was a high level of significance between the initial and final stressed words ($\beta = -23.16$, SE = 8.06, z = −2.87, $p < 0.005$), but there was no significance between the initial and medial stressed words ($\beta = -11.04$, SE = 8.47, z = −1.30, $p = 0.19$). The interaction between the stress positions of initial and medial ($\beta = 3.01$, SE = 13.74, z = 0.22, $p = 0.82$) and initial and final ($\beta = 18.13$, SE = 10.70, z = 1.69, $p = 0.09$) stressed words was not significant for penultimate versus final WORD TYPE. The interaction also didn't show any major effects on the STRESS POSITION between the initial and medial stressed words ($\beta = -12.58$, SE = 12.80, z = −0.98, $p = 0.33$) or the initial and final stressed words ($\beta = 3.40$, SE = 13.39, z = 0.25, $p = 0.80$) for the antepenultimate versus final WORD TYPE.

Pairwise comparisons for the canonical initial stress position on antepenultimate word type between initial and medial ($\beta = 23.34$, SE = 4.69, z = 4.96, $p < 0.001$) and initial and final ($\beta = 19.96$, SE = 4.35, z = 4.58, $p < 0.001$) stress positions indicated significantly high performances for pupillary responses to unpredictable stress in Turkish. There were significant differences between the medial and initial stress positions for the penultimate WORD TYPE ($\beta = 9.16$, SE = 4.69, z = 1.94, $p < 0.05$), but not between the medial and final stress positions ($\beta = -2.81$, SE = 4.58, z = −0.61, $p = 0.54$). Lastly, pairwise comparisons for the canonical final stress position on final word type between final and initial ($\beta = 21.25$, SE = 4.35, z = 4.88, $p < 0.001$) and final and medial ($\beta = 12.02$, SE = 4.58, z = 2.62, $p < 0.01$) stress positions indicated significance for pupillary responses to predictable stress positions in Turkish.

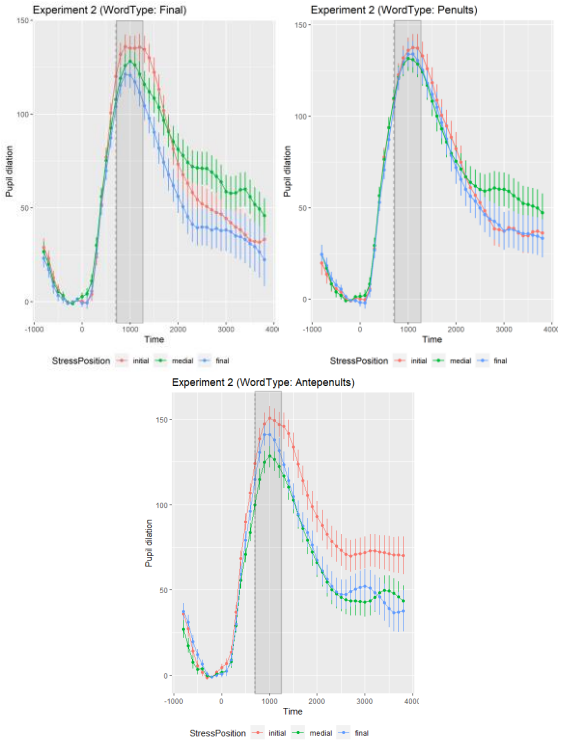


Figure 2: *Pupil dilation across time in Experiment 2.*

5. Discussion and Conclusions

The current study aimed to investigate the PDR to stress perception processing in Turkish native speakers. For this purpose, our study tested whether Turkish speakers have difficulty judging stress shifts for different stress violations and whether their pupillary responses are sensitive to stress processing. Our results with a time window between 700-1300 ms, i.e., beginning from the stimulus offset, indicated that pupil size changes from exceptional stress to a default final position cause increased cognitive processing in Turkish. Our analysis of the speakers' PDRs for Experiment 1 confirmed that the processing effort has reflected a cognitive increase in pupil dilation for stress position in the default final word type that is incorrectly pronounced at initial and medial positions. However, the PDRs of the speakers for the canonical penultimate word type, which is an unpredictable stress position in Turkish, showed no differences for correctly or incorrectly pronounced words in each stress position. Findings revealed that the speakers did not show a cognitive sensitivity for pupillometry to canonical medial stress words, even if they were pronounced correctly or incorrectly when syllable lengths were equal to all three syllables.

Our findings for Experiment 2 indicated a high sensitivity between predictable and unpredictable stress positions for final, penultimate, and antepenultimate word types. The pupillary responses of speakers suggested that a syllable weight effect at the initial position increased their cognitive processing. Our results revealed that the initial stress position, where the syllable weight is manipulated, indicated difficulty in judging stress both in the canonical final and canonical antepenultimate positions. When the pupil diameter in the initial position becomes larger than in medial and final positions in the canonical final word type, it has similar findings in the canonical antepenultimate word type, but the PDRs are larger in incorrectly pronounced final stressed words than incorrect medial stress words. This finding indicated that speakers had difficulty judging the stress shifts in their native language when syllable weights were different. Additionally, the results for the antepenultimate word type, which is expected to be the most unpredictable stress position for Turkish words, showed that speakers had difficulty judging the stress shift both in medial and final stress positions when compared to initial stress positions. In the final word type, which is the most predictable stress position in Turkish, the speakers exhibited an increased PDR both for initial and medial stress positions when compared to final stress positions. However, the pupil diameters did not show a significant effect on the canonical penultimate word type. This is because, as expected, the canonical penultimate word type has an unpredictable stress position in Turkish between the medial and final stress positions. In a similar vein, the PDRs of speakers for the canonical penultimate word type between medial and initial stress positions indicated small significance when compared to other word types.

As well known, Turkish is a default and rule-based final stressed language; however, the canonical penultimate and antepenultimate stress types are accepted as being lexically specified [10, 18]. According to this point of view, while final stressed words with canonical penultimate stress have a lexical deviation, speakers might exhibit less cognitive sensitivity to stress changes that lead to a default stress pattern, as opposed to stress shifts that include lexicalized patterns. A large number of studies have explored how neural correlates of stress processing in speech perception are relevant to "stress deafness" [11, 12, 27, 28] in different languages, including Turkish, but they did not examine the cognitive processing of pupillometry. Domahs and colleagues' study [10] concluded that the neural processing of stress shifts indicated a centroparietal positivity effect (P3b-like response) in Turkish for exceptional stress positions and a negativity effect (N400 response) for default positions. Their results showed that stress predictability in Turkish does not directly contribute to "stress deafness" [11, 12, 27, 28] but is only visible for the predictable and default final stress position. Our PDR findings indicated a higher significance for the exceptional stress position in Turkish when compared to the default position, specifically if there is a syllable weight manipulation. On the other hand, the canonical antepenultimate stressed words, which are accepted as rare to final stressed words in Turkish, revealed that incorrectly pronounced words in exceptional and default stress positions showed a cognitive load. Speakers did not perceive exceptional stress patterns easily when they were pronounced incorrectly, but normally they receive the default stress type in Turkish.

To our knowledge, this is one of the first psycholinguistic studies to use pupillometry to measure the auditory processing of stress perception between default and exceptional stress positions in Turkish. The pupillary results of our study confirmed the previous findings concerning the neural correlates of stress processing in speech perception and speakers' sensitivity to stress judgment processing. In conclusion, Turkish speakers have difficulty judging stress in their typical final stress position, and their pupillary responses show greater sensitivity to stress shifts in the default position compared to exceptional stress positions.

6. Acknowledgements

I would like to thank Özgür Aydın and Karolina Broś for their support during data analysis.

7. References

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