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Özgün araştırma

Türkçe İçin Çok Özellikli Mismatch Negativity Paradigma Geliştirilmesi- Bir Test-Tekrar Test Güvenirlik Çalışması

Eser Sendesen[1], Selin Kargül[2], Meral Didem Türkyılmaz[3]

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Öz

Amaç: Önceki çalışmalar, santral işitsel sistemdeki patolojlerin tanımlanmasında önemli bir rol oynayan MMN' nin her ana dilde farklı yanıtlar oluşturduğunu göstermektedir. Bu nedenle MMN'de kullanılan uyaranlarının ana dillere göre yapılandırılması gerekmektedir. Bu çalışma, Türkçenin akustik özelliklerine uygun konuşma uyaranı içeren çok özellikli bir paradigma geliştirmeyi amaçlamaktadır.
Gereç ve Yöntem: Bu çalışmaya 20-31 yaşları arasında (24.37±3.75) normal işiten 30 katılımcı (15 Erkek, 15 Kadın) dahil edildi. Katılımcıların İşitme eşiği (0.125-8 kHz) 20 dB HL'den düşüktü. MMN yanıtları, 22 yüzey kafa derisi elektrotu ile kaydedildi. Standart uyaran olarak /te/ ve /pi/ konuşma uyaranları seçilmiştir. Beş farklı aykırı uyaran sonucunda (şiddette azalma ve artış, temel frekansta azalma, sürede azalma, ünlü ve ünsüz harf değişimi) ortaya çıkan MMN yanıtlarının genlik ve latans parametreleri değerlendirildi.
Bulgular: Fz elektroduna göre, /te/ ve /pi/ uyaranlarının test-tekrar test MMN yanıtlarının genliği ve gecikmeleri arasında eşleştirilmiş örnek t-testine göre istatistiksel olarak anlamlı bir fark yoktur (p>0.05). Aynı zamanda /te/ ve /pi/ uyaranlarının aykırı uyaranları ile ortaya çıkan MMN yanıtlarının genliklerinde test-tekrar test arasında istatistiksel olarak anlamlı bir ilişki bulundu (p<0.05).
Sonuç: Bu çalışma, anadili Türkçe olanlarda yapılacak MMN uygulamasında anadile uygun konuşma uyaranlarının kullanılmasına, işitsel işleme becerilerinin geleneksel tonal uyaranlara göre daha kapsamlı bir şekilde değerlendirilmesine olanak sağlayacak ve santral işitsel sistemin sağlıklı veya patolojik durumlarında MMN dalga formundaki olası komponent değişikliklerin yorumlanmasına katkı sağlayacaktır.

Anahtar kelimeler: Mismatch negativity; Çok özellikli paradigma ; konuşma uyaranları

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Original Research

Developing a Multi-Feature Mismatch Negativity Paradigm For Turkish- a Test-Retest Reliability Study

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Abstract

Objectives MMN, which is important in defining pathologies in the central auditory system, occur with different responses in each native language. Therefore, it is crucial that the stimuli used in MMN must be structured according to the native languages. This study aims to develop a multi-feature paradigm that includes speech stimulus suitable for the acoustic characteristics of Turkish.
Materıals and Methods Thirty participants (15 Males, 15 Females) with normal hearing between the ages of 20-31 (24.37±3.75) were included in this study. Participants' hearing threshold (0.125-8 kHz) was less than 20 dB HL. MMN responses were recorded from 22 surface scalp electrodes. The speech stimuli /te/ and /pi/ were chosen as standard stimuli. Amplitude and latency parameters of the MMN responses of five different deviants: decrease and increase in intensity, decrease in fundamental frequency, decrease in duration, and consonant and vowel change were evaluated.
Results According to the Fz electrode, there was no statistically significant difference between the amplitude and latencies of the test-retest MMN responses of the /te/ and /pi/ stimulus according to paired sample t-test ($p>0.05$). A statistically significant relationship was found between the test-retest for the /te/ and /pi/ stimulus amplitudes in deviant types ($p<0.05$).
Conclusion This study will enable the use of speech stimuli appropriate to the native language in MMN application to be conducted in native Turkish speakers, allow a more comprehensive evaluation of auditory processing skills compared to conventional tonal stimuli, and contribute to the interpretation of possible component changes in the MMN waveform in healthy or pathological conditions of the central auditory system.

Keywords Mismatch negativity ; Multi-feature paradigm ; Speech stimuli

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Introduction

Auditory evoked potentials (AEPs) are a subset of event-related potentials. Mismatch Negativity (MMN) is a type of auditory evoked potentials. MMN can measure early cortical processes of hearing and speech discrimination. It was defined by Näätänen et al. in 1978. The MMN is obtained by the difference between the responses to the standard stimulus representing the auditory regularity and the response to the deviant stimulus that does not conform to the auditory regularity (Näätänen et al., 1978). In addition, MMN indirectly provides information about the neural representation of the standard stimulus, providing insight into the memory and perceptual functions of the auditory cortex (Näätänen et al., 2007). In adults, it is generally seen as a negative wave that occurs 100-250 ms after the onset of deviation stimuli (Kujala et al., 2007).

MMN is an objective method widely used in cortical auditory processing and auditory discrimination studies (Katz et al., 2015). Since MMN does not require attention or behavioural response, it is suitable for evaluating auditory processing in clinical groups and children (Näätänen et al., 1978). In addition, the MMN can be recorded in a passive listening state; it allows working with a broad population, such as newborns, young children, coma patients, or individuals with autism spectrum disorders who cannot receive or respond to instructions (Cheour et al., 2002; Huotilainen et al., 2005; Kane et al., 2000; Kujala et al., 2005). Also, MMN can be used in psychiatry to monitor drug effects, susceptibility to the disease, and progression of the disease in schizophrenia (Jessen et al., 2001).

In MMN studies using tonal sounds, comparing groups with and without language impairment, no difference was observed between the groups, while a difference was found in MMN responses when using speech stimuli (Uwer et al., 2002). It has also been stated that the amplitude responses in the MMN test using speech stimuli are greater than the produced by non-speech stimuli (Uwer et al., 2002).

It is stated that the early steps of automatic discrimination of speech sounds are based on the existence of LTM traces of native phonemes (Näätänen et al., 1997). Therefore, in the latest studies, MMN obtained with speech sounds is used to investigate the representation of language-specific LTM. These studies show that speech stimuli in the native language elicit greater amplitude MMN responses than non-native stimuli (Partanen et al., 2013; Ylinen et al., 2006). It has been reported that although the MMN amplitude increases as the difference between standard and deviant stimuli increases, this situation may not occur in this order when a speech stimulus is used (Cheour et al., 2000; Ylinen et al., 2006). Studies emphasise that

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phonemes in the native language show an increased MMN response compared to non-native speech stimuli. Similarly, meaningful words show an increased MMN response compared to non-native words. In a study conducted by Pulvermuller et al. in 2001, they observed that meaningful words elicited responses with greater amplitude than meaningless words in the MMN responses they recorded using both meaningful and meaningless words in Finnish (Pulvermüller et al., 2001). These findings support the view that words in native languages have memory traces in the brain.

In MMN, stimuli are traditionally presented using the oddball paradigm. In the classical oddball approach, the recording time is long and gives information about the cortical differentiation of one or two sound features. The 'multi-feature paradigm' developed by Näätänen et al. allows the simultaneous evaluation of five different MMN responses with a shorter recording time (Näätänen et al., 2004).

The constant repetition of the standard stimulus in the oddball paradigm is quite far from daily life. Thanks to the variety of stimuli in the multi-feature paradigm, the natural listening situation in daily life can be achieved better than the oddball paradigm. Especially in speech, it is rare for a sound or syllable to be repeated more than twice in succession, as in the oddball paradigm. In addition, studies show that the multi-feature paradigm is a more suitable method for study in children and many patient groups since it can simultaneously evaluate more than one variable of the auditory stimulus in a shorter time than the traditional oddball paradigm. In addition, with the multi-feature paradigm, it is possible to avoid long recording sessions that negatively affect attention and motivation. For these reasons, the multi-feature array paradigm is encouraged for more reliable MMN studies.

The increase in the variety of stimuli in speech sounds allows researchers to make a more comprehensive assessment of speech perception in language and speech disorders, neurological disorders, and auditory disorders. Also, it is essential that the speech stimuli used in MMN accurately reflect the pre-attentive language skills of individuals at the word level. Considering that MMN with different results in the various native language, it is very important that the stimuli used in MMN can be structured in accordance with the native language. Therefore, this study aims to develop a multi-feature paradigm that includes speech stimulus suitable for the acoustic characteristics of Turkish and to use it in MMN applications.

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Materials and Methods

Participants

The present study was conducted in Hacettepe University Audiology Department. According to the study's eligibility criteria, 30 participants (15 Males, 15 Females) with normal hearing between the ages of 20-31 (24.37±3.75) were included in this study. It was considered that there was no neurological, psychological problem, or language-speech pathology diagnosed in the histories taken from all participants.

The function and appearance of all participants' external and middle ears were examined by otoscopy and tympanometry and defined as normal. Pure tone audiometry was performed in an IAC (Industrial Acoustic Company) soundproof test room with a GSI-61 audiometer, calibrated TDH-39P headphones, and a Radioear B-71 bone vibrator. The behavioural pure tone audiometry threshold levels (0.125-8 kHz) were less than 20 dB HL.

Mismatch Negativity

In this study, the multi-feature paradigm was used (84). This paradigm provides information on five different deviants in a considerably shorter recording time than the traditional oddball paradigm. In this paradigm, each deviant is presented after a standard stimulus. As a result, while the ratio of deviants to the standard is 50%, the ratio of each deviant to the standard is 10%. The stimuli were constructed digitally using the Praat program and were presented binaurally via calibrated Sennheiser earphones with equal phases in both ears.

The speech stimuli /te/ and /pi/ were chosen as standard stimuli. /te/ standard stimulus; it has a length of 170 ms, and intensity of 70 dB SPL and a fundamental frequency (F0) of 113.3 Hz. /pi/ standard stimulus; it has a length of 170 ms, an intensity of 70 dB, and a F0 of 92.36 Hz. Deviant stimuli differ from the standard stimulus in terms of different features such as vowel duration, increase or decrease in stimulus intensity, F0, consonant, and vowel change.

Deviant stimuli for the /te/ standard stimulus were created as follows. Deviant 1 was created by reducing the standard intensity by 7% (63,46 dB), while Deviant 2 was created by increasing the standard intensity by 7% (76,53 dB). Deviant 3 was created with an 8% reduction of the F0 (103.6 Hz). Deviant 4 was created by changing the vowel duration to 100 ms. Deviant 5 is formed by changing the consonant /te/ to /pe/, while Deviant 6 is formed by changing the vowel to /te/, /ti/.

Deviant stimuli for the /pi/ standard stimulus were created as follows. Deviant 1 was created by reducing the standard intensity by 7% (63,46 dB), while Deviant 2 was created by

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increasing the standard intensity by 7% (76,53 dB). Deviant 3 was created with an 8% reduction of the F0 (88.15 Hz). Deviant 4 was created by changing the vowel duration to 100 ms. Deviant 5 is formed by changing the consonant /pi/ to /ti/, while Deviant 6 changes the vowel to /pi/, /pe/.

EEG Recording

EEG recording was performed in a faraday cage test room. Stimuli were presented by Presentation Software (version 15.0 Neurobehavioral Systems, Inc). The EEG was continuously recorded by a NuAmps II Amplifier and Scan 4.2 acquisition software (Neuroscan Inc., Herndon, VA), at a 500 Hz sampling rate, with filters set to 0.5-70 Hz frequency range. In addition to 20 channel EEG cap (EasyCap GMBH, Germany) with silver cup electrodes based on the classical 10-20 system, external electrodes placed on both left and right ear lobes were included in the recordings. The ground electrode is located between Fz and Cz. The right earlobe was chosen as the reference electrode. The conductive gel was applied to the electrodes with a 15-millimetre blunt needle. It is ensured that the impedances are 15 ohms and below. The events related to standard and deviant stimuli sent by the Presentation program were synchronously recorded along with EEG data. Attention was paid to ensure that the environmental conditions during the test and the retest and the time intervals during which the participants were evaluated were similar. The mean time between testing and retesting was 7.33 ± 0.75 days. Participants watched a movie with subtitles on a laptop computer during the test and were asked to avoid motor movements. Ten trials were recorded from each participant in both test-retest situations, five trials with the multi-feature paradigm created for the /te/ phoneme and five with the multi-feature paradigm created for the /pi/ phoneme. A five-minute rest period was given between each trial. The recording time for each trial is 320 seconds.

Processing of EEG Data

For MMN amplitude and latency evaluations, EEG Lab and ERP Lab programs operating under the "MATLAB" program were used. For each participant, the amplitudes were calculated by subtracting the standard stimulus Auditory Evoked Potentials (AEP) from the deviant stimulus AEP. AEPs were averaged in the (-100)-(+100) μV range after artefact rejection. The negative peak in the waveform that emerged after these processes were accepted as the MMN amplitude value. In the latency evaluations, the range of 150-300 ms was selected using the same program. The value at the peak of the MMN response amplitude was accepted as the latency value. Data analysis was performed within a -50 ms and 450 ms window. In data

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analysis, a 50 Hz notch filter was used. Also, their averages have been extracted from all MMN curves in baseline correction.

Statistical Analysis

The G*Power program was used to determine the sample size in the study. Based on the power analysis, this study should include a minimum of 26 participants to detect a clinically significant outcome with a 5% type I error level and 95% power. The SPSS version 23.0 (IBM Inc., Armonk, NY, USA) package program was used to evaluate the data amplitudes, and latencies of MMN responses. Test-retest data had a normal distribution. Whether there is a significant difference between the amplitude and latency values of MMN responses, test, and retest situations, was investigated with the paired samples t-test. Also, the intraclass correlation coefficient and Pearson's correlation coefficient examined whether there is a significant correlation between the amplitude and latency values of the MMN responses between the test-retest conditions. Descriptive statistically mean (mean) and standard deviation (SD) values are given. A p-value <0.05 was considered statistically significant.

Results

MMN Responses From Participants Revealed by Test-Retest

The amplitudes and latencies of the MMN responses of deviant stimuli in test-retest situations are given in Tables 1 and 2, respectively. In addition, statistical differences (using paired sample t-test) and correlation (using intraclass and Pearson correlation coefficient) evaluations of MMN responses for /te/ and /pi/ stimuli are given in the same tables.

According to paired sample t-test, there was no statistically significant difference between the amplitude and latencies of the test-retest MMN responses of the /te/ and /pi/ stimulus ($p>0.05$). For the /te/ stimulus amplitudes in test-retest conditions, a statistically significant relationship was found for the F0, decrease in duration and vowel change according to intraclass and Pearson correlation coefficient ($p<0.05$). On the other hand, by the same statistical methods for the /te/ stimulus latencies, a statistically significant relationship was found between F0 and vowel change ($p<0.05$).

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Table 1 Amplitudes of the MMN responses of the six deviants according to Fz electrode for the /te/ and /pi/ stimuli and their statistical evaluations

Variable	Stimuli	Amplitude (µV)						
		Test	Re-Test	P-value*	ICC	P-value	r	P-value
D1	/te/	-1,89±1,95	-2.01±1.74	0.76	0.40	0.08	0.24	0.20
	/pi/	-1.69±1.82	-2.23±1.82	0.16	0.49	**0.03**	0.34	0.06
D2	/te/	-3.62±2.32	-2.86±1.88	0.15	0.14	0.34	0.09	0.61
	/pi/	-2.25±1.94	-2.50±1.86	0.52	0.53	**0.02**	0.35	0.056
D3	/te/	-3.74±1.72	-3.52±1.50	0.49	0.61	**0.005**	0.44	**0.01**
	/pi/	-4.09±2.15	-3.83±1.91	0.55	0.52	**0.02**	0.34	0.06
D4	/te/	-3.87±2.18	-3.64±1.75	0.49	0.71	**0.00**	0.56	**0.001**
	/pi/	-3.11±1.86	-3.09±1.25	0.94	0.56	**0.01**	0.40	**0.02**
D5	/te/	-1.70±1.42	-1.50±1.54	0.56	0.32	0.14	0.18	0.33
	/pi/	-2.89±1.95	-2.95±1.51	0.83	0.72	**0.00**	0.57	**0.01**
D6	/te/	-3.84±1.89	-3.19±1.92	0.88	0.58	**0.009**	0.44	**0.01**
	/pi/	-2.97±2.07	-3.15±2.19	0.62	0.72	**0.00**	0.55	**0.01**

D1: Decrease in intensity, D2: Increase in intensity, D3: Decrease in fundamental frequency, D4: Decrease in duration, D5: Consonant change, D6: Vowel change, ICC: Intraclass correlation coefficient, r: Pearson's correlation coefficient
*****Paired samples t-test

For the /pi/ stimulus amplitudes of MMN responses in test-retest conditions, a statistically significant relationship was found for all deviant stimuli according to the intraclass correlation coefficient ($p<0.05$). When the /pi/ stimulus amplitudes are evaluated by the Pearson correlation coefficient, a statistically significant relationship was found for the decrease in duration, consonant change and vowel change ($p<0.05$). On the other hand for the /pi/ stimulus latencies, a statistically significant relationship was found between the intraclass and the Pearson correlation coefficient for the F0 and consonant change ($p<0.01$).

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Table 2 Latencies of the MMN responses of the six deviants according to Fz electrode for the /te/ and /pi/ stimuli and their statistical evaluations

Variable	Stimuli	Latencies (ms)						
		Test	Re-Test	P-value*	ICC	P-value	r	P-value
D1	/te/	222.53±63.47	233.73±52.10	0.44	0.16	0.31	0.08	0.65
	/pi/	202.80±59.45	223.93±66.36	0.22	-0.28	0.75	-0.11	0.53
D2	/te/	242.13±41.35	247.60±30.38	0.57	-0.09	0.59	-0.06	0.75
	/pi/	250.87±39.35	240.00±44.02	0.34	0.13	0.34	-0.11	0.56
D3	/te/	215.53±26.64	247.60±30.38	0.55	0.73	**0.00**	0.63	**0.00**
	/pi/	229.80±39.74	231.33±31.43	0.80	0.71	**0.00**	0.56	**0.00**
D4	/te/	265.60±43.24	271.73±21.55	0.50	-0.08	0.58	-0.06	0.73
	/pi/	266.47±36.17	265.20±26.49	0.86	0.26	0.20	0.14	0.45
D5	/te/	164.33±56.34	166.07±58.32	0.89	0.40	0.08	0.24	0.20
	/pi/	164.80±26.83	169.87±26.17	0.17	0.83	**0.00**	0.71	**0.00**
D6	/te/	231.60±35.79	219.87±32.71	0.10	0.50	**0.02**	0.36	**0.04**
	/pi/	250.93±42.95	253.13±45.24	0.82	0.44	0.06	0.26	0.15

D1: Decrease in intensity, D2: Increase in intensity, D3: Decrease in fundamental frequency, D4: Decrease in duration, D5: Consonant change, D6: Vowel change, ICC: Intraclass correlation coefficient, r: Pearson's correlation coefficient
*****Paired samples t-test

The MMN waveforms resulting from different deviant stimuli are shown in Figures 1 and 2 for the /pi/ stimulus and in Figures 3 and 4 for the /te/ stimulus. Blue waves indicate the first MMN application waveform (test), while green waves indicate the second MMN application waveform (retest). All ERPs were derived from the Fz, Cz, and Pz electrodes. On the X-axis, the window with a width of -50 – 400 ms shows the duration, and on the Y-axis, the wave's amplitude with μV.

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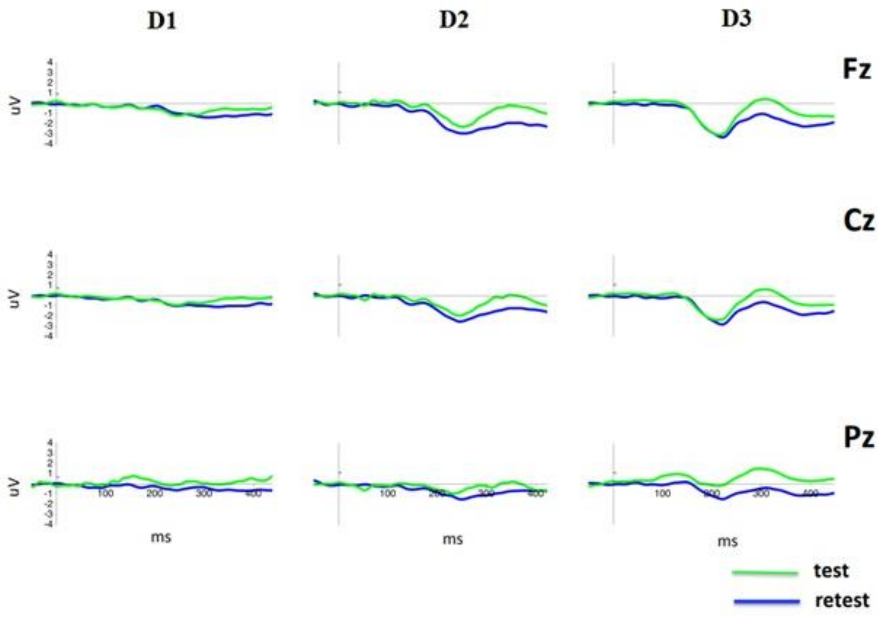
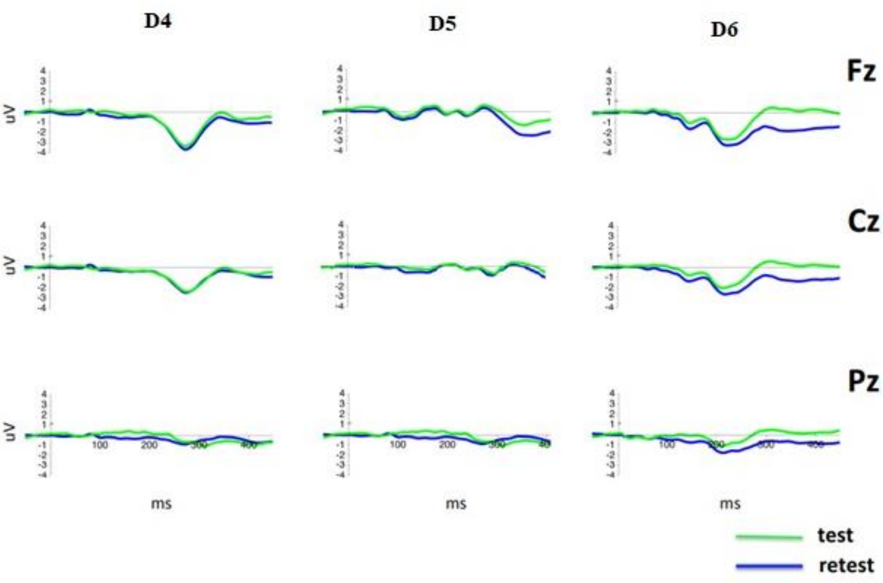


D1: Decrease in intensity, D2: Increase in intensity, D3: Decrease in fundamental frequency,
std: Standart stimuli, dev: Deviant stimuli, Fz: Frontal, Cz: Central, Pz: Parietal

Fig. 1 MMN waveforms belonging to participants (n=30) the resulting from different deviant stimuli (D1,D2,D3) for the /te/ stimulus



D4: Decrease in duration, D5: Consonant change, D6: Vowel change, std: Standart stimuli,
dev: Deviant stimuli, Fz: Frontal, Cz: Central, Pz: Parietal

Fig. 2 MMN waveforms belonging to participants (n=30) the resulting from different deviant stimuli (D4,D5,D6) for the /te/ stimulus

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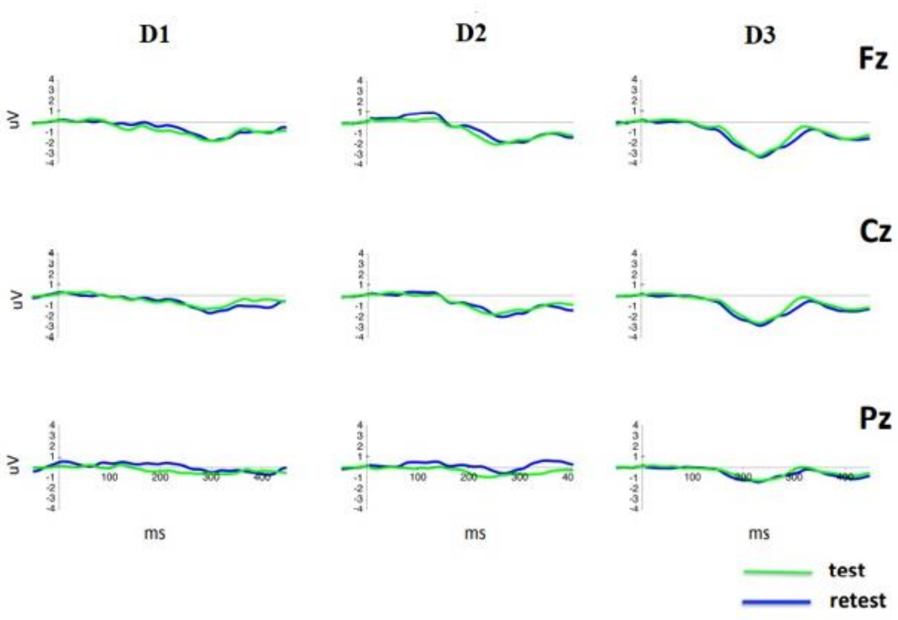
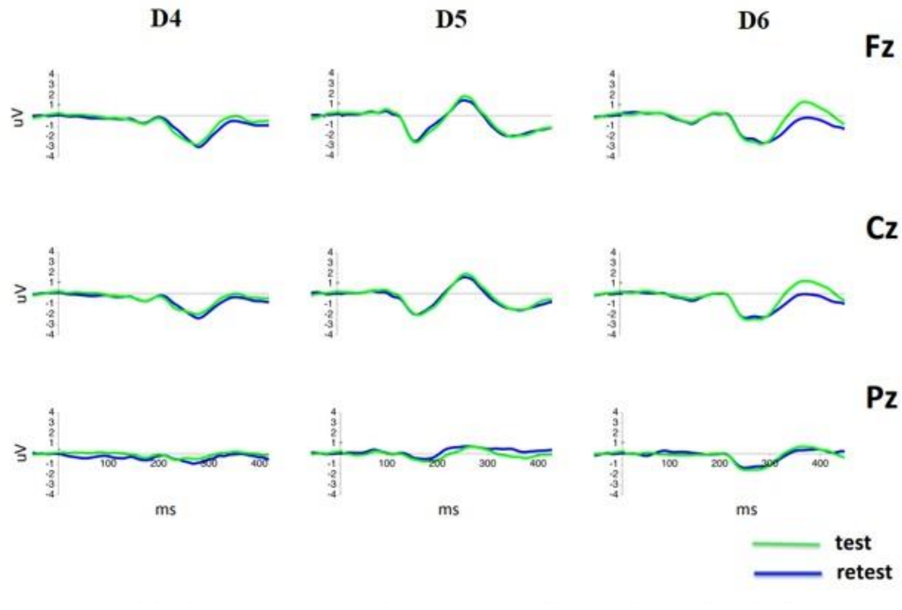


D1: Decrease in intensity, D2: Increase in intensity, D3: Decrease in fundamental frequency,
std: Standart stimuli, dev: Deviant stimuli, Fz: Frontal, Cz: Central, Pz: Parietal

Fig. 3 MMN waveforms belonging to participants (n=30) the resulting from different deviant stimuli (D1,D2,D3) for the /pi/ stimulus



D4: Decrease in duration, D5: Consonant change, D6: Vowel change, std: Standart stimuli,
dev: Deviant stimuli, Fz: Frontal, Cz: Central, Pz: Parietal

Fig. 4 MMN waveforms belonging to participants (n=30) the resulting from different deviant stimuli (D4,D5,D6) for the /pi/ stimulus

Discussion and Conclusion

The emergence of MMN responses as a result of all deviant stimuli in the multi-feature paradigm shows that participants' central hearing systems can distinguish the acoustic changes at the preattention level. MMN studies in the literature indicate that the MMN response can be recorded most reliably from the Fz, F3 and F4 electrodes located in the fronto-central areas (Kujala et al., 2007). For this reason, we made all amplitude and latency evaluations in this study according to the Fz electrode. In test-retest MMN evaluations recorded with multi-feature paradigm using /te/ and /pi/ stimuli, no difference was found between the two tests in terms of amplitudes and latencies ($p>0.05$).

When the the /te/ stimulus MMN amplitudes were evaluated, it was seen that the highest amplitude values belonged to the duration deviant stimulus. On the other hand, for the /pi/ stimulus, the highest amplitude values belonged to the F0 deviant stimulus. The presence of different MMN amplitudes for different types of deviant stimulus is thought to be the result of MMN generation processes' power that depends on the magnitude of the deviations (standard and deviant stimulus difference). It was stated that MMN production areas vary according to the deviant type, resulting in the formation of different amplitudes. At the same time, MMN amplitudes may vary in different electrodes due to the difference in MMN production areas. This leads to different MMN amplitudes even when the acoustic difference between the standard and the deviant stimulus is perceptually similar (Giard et al., 1990). In a study conducted in line with this view, MMN responses that emerged with all deviant stimuli showed a decrease in the frontal region compared to the control group. On the other hand, in the MMN responses associated with the mastoid areas, a decrease was observed only for the duration-deviant stimulus (Todd et al., 2003). In another study, equally distinguishable different deviant stimuli (frequency, intensity, direction, and stimulus-onset asynchrony) were designed. Their study investigated whether these stimuli have similar MMN amplitudes stated that the response to the frequency deviant stimulus on the Fz electrode was higher amplitude. Researchers reported that the increased response in Fz may be related to resource orientation. It has been stated that different stimulus features may have different bipolar orientations, resulting in different amplitude sizes in the fronto-central areas (Giard et al., 1995).

Consistent with the results of the current study, it was stated that duration and F0 deviant stimuli amplitudes are found to be higher in MMN studies in the literature (Lovio et al., 2009; Pakarinen et al., 2009; Pakarinen et al., 2007; Pakarinen et al., 2013). Also, in these studies, it was observed that the duration deviant stimulus amplitudes were larger than the other deviant stimuli. It is stated that there may be three reasons for this result. Firstly, the magnitude of the duration of the deviant stimulus is better distinguishable than other deviants. Secondly, the phoneme duration may be significant in lexical meaning. Thirdly, the change of vowel duration

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in Turkish can change the word's meaning in some words. But rather than that, it changes the intelligibility of the Word (Demirezen, 2012). The syllable pairs we used in the current study are not meaningful words, but the vowel duration in the deviant stimulus we created is quite brief for Turkish. Therefore, we think that the change in short-term stimuli may be more noticeable in this study. As a result, high-amplitude responses are obtained in the duration deviant stimuli.

Considering the MMN amplitudes elicited by the intensity deviant stimulus (decrease and increase in intensity), it was recorded with a lower amplitude than other deviant stimuli. This is a common finding in the literature in studies conducted with the multiple feature array paradigm (Pakarinen et al., 2010; Pakarinen et al., 2007). This is explained by residual intensity variations in the stimulus sequence in the literature (Pakarinen et al., 2013). On the other hand, in the present study, the duration deviant for the /te/ stimulus and the F0 deviant for the /pi/ stimulus revealed a higher MMN amplitude than the other stimuli. In the previous MMN studies, the /te/ and /pi/ stimuli were evaluated as a single data, not separately. However, the F0 deviant stimulus was different for both stimuli (/te/ and /pi/). Therefore, since MMN responses may differ for both stimuli, different deviant stimuli may have produced the highest MMN response in the present study.

When the MMN latencies recorded with /te/ and /pi/ stimuli were evaluated, it was observed that the latest latency belonged to the duration deviant and the earliest latency to the consonant change deviant for both stimuli. In MMN studies, it is generally stated that the deviant stimulus with the highest amplitude value has the shortest latency (Näätänen & Winkler, 1999; Pakarinen et al., 2013). On the other hand, in the study of Naatanen et al. (Pakarinen et al., 2007) in 2007, although the MMN responses that emerged with the duration deviant were of the highest amplitude, the latency of this deviant stimulus was not found to be shortest. The same situation was found for the intensity deviant stimulus. It has been suggested that the reason for this situation may be the delay of the N1 response due to the poor perception of these deviant stimuli (lower intensity, less duration, etc.). In the current study, it is seen that while the duration-deviant stimulus complies with this rule, the intensity-deviant stimulus did not. There could be several reasons for this. The present study determined wave latencies as the point with the highest amplitude value. However, some studies calculate MMN latency using the area under the curve. The fact that MMN latency is calculated with different methods in different studies may change the obtained latency values. In addition, it is emphasized in the literature that latencies can be affected more by individual factors than amplitudes (Paukkunen et al.,

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2011; Sendesen et al., 2021). The influence of interindividual factors on latencies may create variable latency results in studies conducted in different regions. As a result of these reasons, it was thought that there were deviant stimuli that did not fully comply with the latency intensity function in the present study.

Another target of the study was to evaluate the relationship between the test-retest of the participants. According to the correlation analysis between the test-retest amplitudes, there is a relationship in terms of F0, duration, and vowel change for the /te/ stimulus, all deviant stimuli for the /pi/ stimulus. On the other hand, for the latencies, there is a relationship in terms of the F0 and vowel change deviant stimuli for the /te/ stimulus, F0 and consonant change deviant stimuli for the /pi/ stimulus. We think that the number of deviant stimuli found to be correlated in test-retest is lower for latencies than amplitudes may be related that MMN latency gives more variable results than amplitudes. As a result, it is less reliable. As mentioned above, latencies are more affected by individual factors than amplitudes. Although attention is paid that the test conditions are the same during the test-retest and that factors such as the individual's eye movements, skin impedance, and sleep state do not change, many studies have emphasized that the latency values are highly affected by individual factors (Javitt et al., 1998; Näätänen et al., 2007; Oken et al., 2006; Wang et al., 2003)

The present study investigated the test-retest reliability of MMN responses to 6 different deviant stimuli using speech sounds with the multi-feature array paradigm. It was found that while all MMN deviant amplitudes with the /pi/ stimulus in the test-retest were similar, only the F0, duration and vowel change deviants were similar with the /te/ stimulus. According to these results, in the MMN with a multi-featured paradigm, although there are no statistically significant differences between test-retest in terms of MMN amplitudes, more reliable results will be obtained using /pi/ stimulus instead of /te/. Another result was that although there was no statistically significant difference between test-retest for MMN latencies, MMN amplitudes were more similar than latencies in the test-retest application. Accordingly, amplitude evaluation rather than latency may give more reliable results during a speech MMN application analysis. As a result, this paradigm, which includes speech sound stimuli instead of conventional tonal stimuli, and whose test-retest reliability for Turkish has been proven in this study, will be beneficial in clinical studies such as auditory discrimination in language and speech disorders, electrophysiological evaluation of the effectiveness of auditory training, and evaluation of language-specific phoneme categories. Also, this study will enable the use of speech stimuli appropriate to the native language in MMN application to be conducted in native

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Turkish speakers, allow a more comprehensive evaluation of auditory processing skills compared to conventional tonal stimuli, and guides in determining which potential differences in MMN components are worth considering.

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Conflict of interest

The authors declare that they have no confict of interest.

Ethical approval

Ethical approval for this study was obtained from Non-Interventional Clinical Research Ethics Committee (GO15/21) and completed in conformity with the standards set by the Declaration of Helsinki.

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