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Original Research

The Effect of Different Noise Maskers and Speech Understanding in Noise on Auditory Cortical N1 Response

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Abstract

Objectives: The aim of this study is to investigate the effect of different noise types at different signal to noise ratios(SNR) on sound onset and sound change evoked N1 responses among normal hearing individuals with different speech in noise abilities.
Materials and Methods: 30 participants aged between 18-30 are included in the study. Participants were divided into two groups based on median value of the scores obtained in speech in noise test. In electrophysiological measurements the stimulus /ui/ was presented in quiet, and in white noise and ICRA noise under two SNRs. Sound onset and sound change evoked N1 latencies and N1-P2 amplitudes were compared between conditions and groups.
Results: White sound onset N1 latencies were prolonged in both noise types under both SNRs, N1-P2 amplitudes were lower in ICRA noise under both SNR conditions compared to quiet. Latencies and amplitudes at the same SNR under ICRA noise were higher and lower respectively compared to white noise. Sound change N1 latencies were higher at +10dB SNR ICRA noise and +5dB SNR white noise compared to quiet, N1-P2 amplitudes were lower at ICRA +5dB, +10dB SNR and at white noise +5dB SNR compared to quiet. In between group comparisons sound onset N1-P2 amplitudes of group-2 were higher than group-1 at white noise +5dB SNR, no relationship between speech in noise scores and cortical responses was found.
Conclusion: The presence of noise change the sound onset and sound change N1 responses, the effect of noise types changes based on the evoked response.

Key Words: *speech in noise, cortical N1 response, steady noise, variable noise.*

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Introduction

The P1- N1- P2 complex includes a series of positive and negative peaks that occur at the onset of the sound upon stimulus delivery (Brett A Martin et al., 2007). P1-N1-P2 responses, which provide information about the integrity of auditory pathways and the neural encoding of sound beyond the brainstem, are recently used to assess suprathreshold auditory skills such as speech perception (Martin et al., 2008). Acoustic Change Complex (ACC), which is observed as a temporally locked second waveform following the P1, N1 and P2 evoked by the onset of sound, is the cortical auditory evoked potential that emerges with a change in an ongoing sound (Martin & Boothroyd, 1999). The ACC, specified as the encoding of distinguishable information in the auditory cortex, is obtained as a response to spectral and intensity changes in speech or speech-like stimuli. ACC can be reliably recorded and is considered as a sensitive indicator of detecting change in an ongoing signal (Boothroyd et al., 2010).

Depending on the presence of noise, changes occur in higher level neural functions. Difficulty in understanding speech in the presence of background noise becomes increasingly severe as background noise levels increase (signal-to-noise ratio –SNR decreases). As with speech recognition performance, neural responses weaken with increasing noise(Billings et al., 2017). Related to this, in studies on Cortical Auditory Evoked Potentials (CAEP), the effect of noise was observed as lower amplitude values, prolonged latencies, and changes in morphology compared to responses obtained in quiet (Ganapathy & Manjula 2016; McCullagh et al., 2012). For example, Whiting et al. (1998) showed that the N1 response was least affected by the presence of noise, whereas N2 response was more affected by the presence of noise. As the broadband noise masking level increased, the N1 and P3 amplitudes decreased and their latencies increased (Whiting et al., 1998). Ganapathy and Manjula (2016), on the other hand, stated that the ACC wave morphology deteriorated with the increase in noise levels, and that the sound onset response in noise was more affected than the ACC response(Ganapathy & Manjula 2016).

It was observed that the ability to discriminate speech in noise is related to CAEPs obtained in the presence of noise. For example, in the study of Anderson et al. (2010) N2 amplitudes of the participant group with lower speech in noise scores increased under noise condition. The authors stated that the reason for this may be related to low group participants utilizing more neural resources when processing speech in noise (Anderson et al., 2010).

In the studies examining the effects of noise on CAEPs, it is stated that the noise type is crucial along with the spectral properties and periodicity differences of the stimuli presented in noise.. For example, Niemczak and Vander Werff (2019) found that babble noise affects the

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evoked potentials with the stimulus /ui/ more than speech shaped noise (SSN), causing a greater decrease in N1-P2 amplitudes. Similar to Niemzcak and Vander Werff (2019), Mamoor and Billings (2017) reported that SSN presentation resulted in larger amplitudes and decreased latencies compared to four talker babble noise and one talker modulated noise. In another study, Billings et al. (2011) compared four types of noise and stated that the noise containing speech sounds was the noise that prolonged the sound onset N1 latency the most.

In the light of the previous studies, the present study aimed to examine the effects of different noise types on sound onset and sound change evoked cortical responses in two participant groups with different speech in noise abilities.

Materials and Methods

Ethical permission for the study was obtained from Hacettepe University Non-Interventional Clinical Research Ethics Committee (GO19/118). The participants were informed about the scope and purpose of the study. Written consent was obtained.

A total of 34 participants, 17 males and 17 females, between the ages of 18-30, with normal hearing, were involved in the study. Because of excessive artifacts in the CAEP records, a total of 4 participants (2 females and 2 males) were not included in the statistical analysis. CAEP was applied to 15 (50%) women and 15 (50%) men. The mean age of the participants was 22.83±3.85 years.

Speech in Noise Test- SIN

Digital recording of a monosyllabic word list (Akşit 1994) was presented at 65 dB SPL via a laptop computer connected to audiometer while speech shaped noise (SSN) was presented from the same speaker at -5 dB signal to noise ratio (SNR) located 0 degree Azimuth. 50 words were presented to the participants, and 2 points were given for each correct answer. After the participants SIN scores were ranked, the median value (Md=73) was computed and two groups were determined as "upper and lower groups"(Anderson et al., 2010). The upper group was named 'group-1' and the lower group was named 'group-2'.

Stimuli used in CAEP assesment

/ui/ stimulus: The stimulus /ui/ was adapted from Martin and Boothroyd (2000) and prepared with Praat software(Boersma, 2001). Formant values were 150 Hz, 300 Hz, and 3000 Hz, for F0, F1 and F3 respectively throughout the stimulus. The second formant frequency of the stimulus F2 was 900 Hz at the beginning of the stimulus and then increased to 2400 Hz. The total length of the stimulus is 1000 ms.

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speech-like modulation of voice. Produced as a series of noise signals that can be used in the hearing aid for real ear measurements and psychophysical assessment, ICRA noise contains spectrums shaped by gender and vocal effort, simulating one or more speakers(Dreschler et al., 2001).

White Noise: The white noise used in the study was obtained using the Praat program (Boersma, 2001). White noise, which is used for masking frequencies in the range of 100-8000 Hz, carries equal acoustic energy at all frequencies(Hawkins Jr & Stevens, 1950).

Electrophysiological Tests

Electrophysiological evaluations were performed in a Faraday caged room using 20-channel recording with Neuroscan EEG 4.3 system *(Singen, GERMANY)*. The participants sat on an armchair and watched a muted movie without subtitles, while stimuli were presented through a loud speaker 1 meter in front of the participant through the Neurobehavioral System-Presentation program under different conditions. Auditory potentials were recorded by presenting /ui/ stimulus at 65 dB in quiet *(5-only the stimulus /ui/ is presented without background noise)*, +5 dB SNR and +10 dB SNR white noise, +5 dB SNR and +10 dB SNR ICRA noise conditions. Total of 100 stimuli was delivered in each condition.

20 channel EEG cap was used, silver cup electrodes were placed on both ear lobes were used as reference electrodes, Fpz channel was used as ground electrode. Evoked potentials were obtained by applying 0.1-30 Hz band-pass filter, 50 Hz notched filter, and ±100 µv artifact rejection to the raw EEG recordings, and epoched within -100 ms/1400 ms window. Averaged data were analyzed using EEG Lab (Delorme & Makeig, 2004) and ERP Lab (Lopez-Calderon & Luck, 2014) programs.

By averaging the individual waveforms obtained under different conditions, averaged waveforms of all participants from the Cz electrode for each condition were obtained. Sound onset N1 and P2 responses, and ACC N1 and P2 responses were marked in these waveforms. Individual peak detection windows were created within ±50 ms of avaraged waveform peak latencies. Maximum negative and positive peaks in these latency ranges in individual waveforms of each participant were automatically marked as N1 and P2 responses using EEG Lab and ERP Lab programs and verified by observers. As a result, N1 response latencies and N1- P2 peak-to-peak amplitudes for sound onset and ACC were obtained for statistical analysis.

Statistical Analysis

Analyzes were made with IBM SPSS Statistics 22.0 program. The differences in the N1 latency and amplitude values of the groups in different conditions were evaluated with independent samples by t-test, and the N1 latency and amplitude values of the individuals were

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compared with the repeated measures ANOVA between conditions, regardless of group. Bonferroni corrections were applied in pairwise comparisons in post-hoc evaluations and used in comparisons between groups. Besides, correlational analysis was performed between latency-amplitude values and SIN values.

Results

The mean and standard deviation values of the sound onset and ACC N1 latencies and N1- P2 peak-to-peak amplitudes of the individuals in each condition are given in Table 1.

Table 1. Descriptive statistics of measurements from 30 participants.

	Min-Max	**Mean±SD**
SIN (-5 dB SNR)	58-88	72,4±8,26
onset ICRA noise +5 dB SNR N1 lat.	146-206	184±15,58
onset ICRA noise +10 dB SNR N1 lat.	158-210	184,2±10,4
onset white noise +5 dB SNR N1 lat.	148-184	163,6±7,58
onset white noise +10 dB SNR N1 lat.	138-180	160±8,3
onset quiet N1 lat.	142-172	172±8,89
onset quiet N1-P2 amp.	-13,44-(-1,62)	-6,04±2,79
onset ICRA noise +5 dB SNR N1-P2 amp.	-6,77-0,22	-3,39±1,5
onset ICRA noise +10 dB SNR N1- P2amp.	-6,52-(-1,13)	-3,75±1,48
onset white noise +5 dB SNR N1-P2 amp.	-12,49-(-2,54)	-5,67±2,35
onset white noise +10 dB SNR N1-P2 amp.	-10,89-(-2,73)	-5,83±2
acc ICRA noise +5 dB SNR N1 lat.	600-730	672,33±28,84
acc ICRA noise +10 dB SNR N1 lat.	732-677,86	677,86±26,21
acc white noise +5 dB SNR N1 lat.	602-750	673,2±34,45
acc white noise +10 dB SNR N1 lat.	616-750	674,33±31,12
acc quiet N1 lat.	610-716	657,90±23,32
acc ICRA noise +5 dB SNR N1-P2 amp.	-3,35-(-3,33)	-1,59±0,95
acc ICRA noise +10 dB SNR N1-P2 amp.	-3,46-0,04	-1,64±0,94
acc white noise +5 dB SNR N1-P2 amp.	-3,64-0	-1,46±0,88
acc white noise +10 dB SNR N1-P2 amp.	-4,27-3.35	-1,67±1,27
acc quiet N1-P2 amp.	-4.76-(-0,76)	-2,52±1,04

(SIN scores are in percentage, latencies are in ms and, amplitudes are in mV)

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Average Waveforms

The average waveforms of participants in quiet and white noise conditions are shown in Figure 1. The waveforms in quiet and ICRA noise conditions are shown in Figure 2.

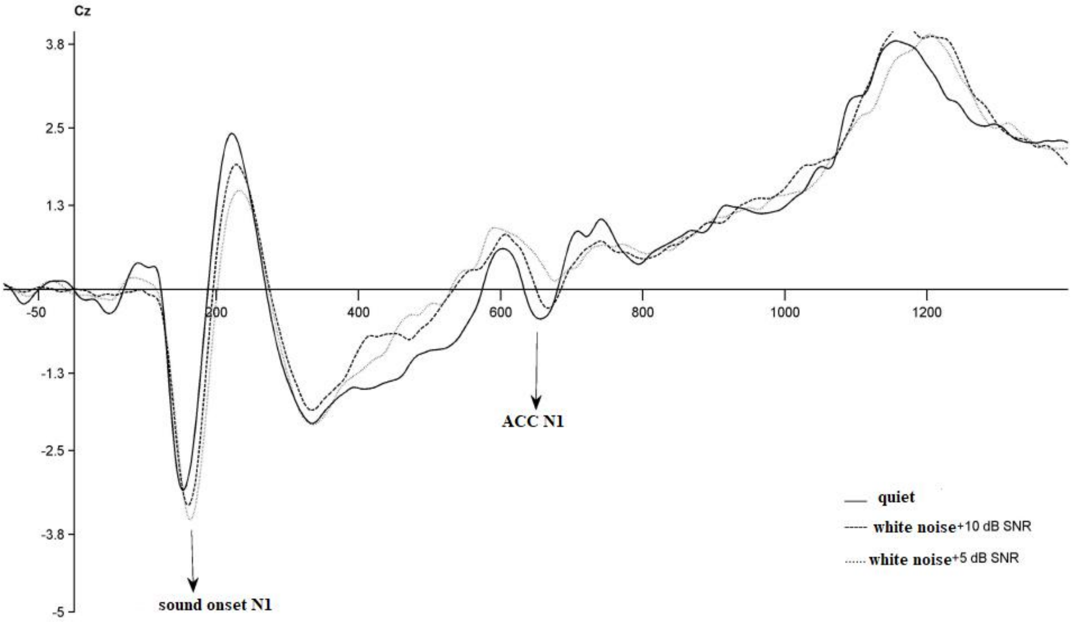

Figure 1. Quiet and white noise conditions

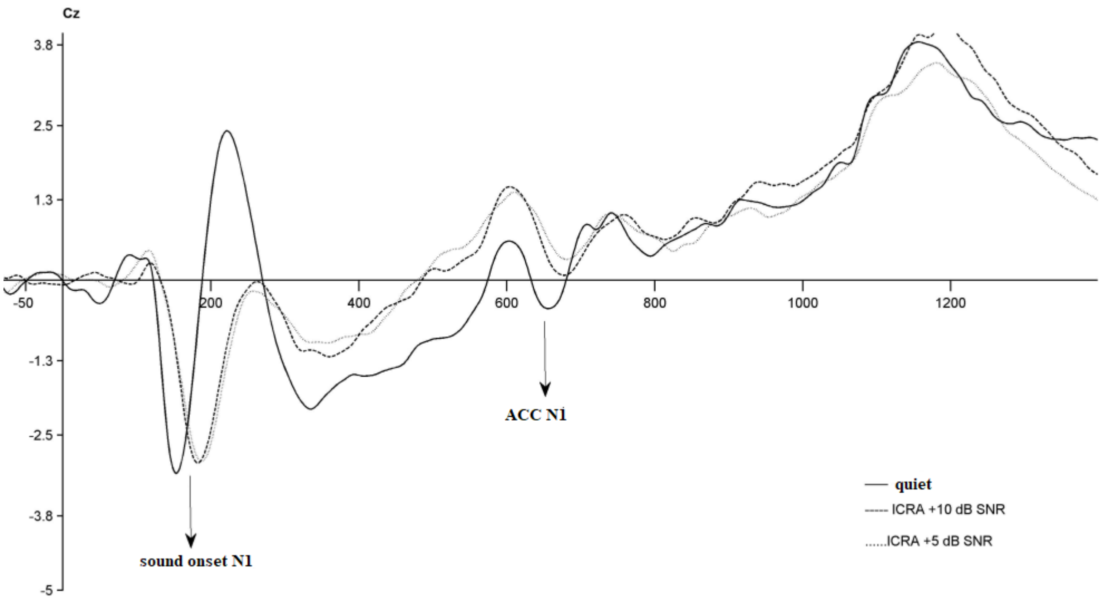

Figure 2. Quiet and ICRA noise conditions

Effect of noise on sound onset N1 latencies

It was observed that there was a significant difference between the sound onset N1 latencies in different conditions ($p<0.001$). In paired comparisons, the onset N1 latencies of

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white noise were found to be significantly higher at +10 dB and +5 dB SNR compared to the quiet. Similarly, N1 latencies in ICRA noise was significantly higher at +10 dB SNR and +5 dB SNR compared to the quiet (p<0.001). When different SNRs within the same noise type are compared, N1 latencies did not differ significantly between ICRA noise +5 dB SNR and ICRA noise +10 dB SNR and between white noise +5 dB SNR and white noise +10 dB SNR (p>0.05 and p=0.247).

When different noise types are compared under the same SNR, the onset N1 latencies were found to be significantly higher in the +5 dB SNR ICRA noise condition than in the +5 dB SNR white noise condition (p<0.001). Similarly, latencies were significantly higher at +10 dB SNR ICRA noise than +10 dB SNR white noise (p<0.001).

Effect of noise on sound onset N1-P2 peak-to-peak amplitudes

N1-P2 peak-to-peak amplitudes differed significantly between conditions (p<0.001). In pairwise comparisons, the sound onset N1-P2 amplitudes were not significantly different between the quiet and the white noise +5 dB SNR and +10 dB SNR conditions (p>0,05). However, the amplitudes were significantly lower at +5 dB SNR and +10 dB SNR conditions for ICRA noise compared to the quiet (p>0,05). When the amplitudes were compared at different SNRs within the same noise type, no significant difference was found between the white noise +5 dB SNR and +10 dB SNR and the ICRA noise +5 dB SNR and +10 dB SNR conditions (p>0,05).

When the effects of different noises were examined in the same SNR, it was observed that the amplitudes were significantly lower at ICRA noise +5 dB SNR condition than white noise +5 dB SNR condition (p<0.001). Similarly, amplitudes were significantly lower at ICRA noise +10 dB SNR condition than white noise +10 dB SNR condition (p<0.001).

Effect of noise on ACC N1 latencies

It was observed that there was a significant difference between ACC N1 latencies obtained under different conditions (p=0.005).

In paired comparisons, ACC N1 latencies were found to be significantly higher in the ICRA noise +10 dB SNR condition than in the quiet (p= 0.004). Similarly, latencies were found to be significantly higher in white noise +5 dB SNR condition than in quiet (p=0.04). There was no significant difference between other conditions (p>0.05).

It was observed that the latencies did not differ significantly between ICRA noise +5 SNR and ICRA noise +10 dB SNR, and between white noise +5 SNR and white noise +10 SNR (p>0,05). When the effects of different noise types were examined in the same SNR, no significant difference was found between ICRA noise +5 dB SNR and white noise +5 SNR,

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and between ICRA noise +10 dB SNR and white noise +10 dB SNR (p>0,05).

Effect of noise on ACC N1-P2 peak-to-peak amplitudes

There was a significant difference in ACC N1-P2 amplitudes between conditions (p=0.001). In pairwise comparisons, peak-to-peak amplitudes of ACC N1-P2 were observed to be significantly lower at ICRA noise +5 dB SNR and ICRA noise +10 dB SNR compared to the quiet (p=0.000 and p=0.009, respectively). Similarly, the amplitudes at white noise +5 dB SNR were significantly lower than the quiet (p=0.001). However, amplitudes were not significantly different between white noise +10 dB SNR and quiet (p=0.059).

When different SNRs were compared within the same noise type, the amplitudes were not significantly different between ICRA noise +5 dB SNR and ICRA +10 dB SNR, and between +5 dB SNR and white noise +10 dB SNR (p>0,05). When the effects of different noises were examined in the same SNR, the amplitudes were not significantly different between ICRA noise +5 dB SNR and white noise +5 dB SNR, and between ICRA noise +10 dB SNR and white noise +10 dB SNR (p>0,05).

Statistical Analysis Between Groups

Participants with SIN score above the median value (Md=73) were arranged as group-1, and those who scored below the median value were determined as group- 2(Anderson et al., 2010).

N1 latency and amplitude values of the groups under different conditions were compared by t-test for independent samples. Sound onset N1-P2 peak-to-peak amplitudes of group-2 were found to be significantly higher than group-1 in the white noise +5 dB SNR condition (p=0.027, d=0.91). No significant difference was observed in other conditions (p>0.05).

Correlations of behavioral and electrophysiological data

The relationship between the SIN test scores and evoked responses was evaluated with Pearson correlation analysis, and no significant correlation was found in any condition (p >0.05).

Discussion

The use of electrophysiological tests together with behavioral tests in the evaluation of the ability to understand speech in noise has previously been stated to support behavioral findings, and studies conducted in this direction also provide us with information about the speech understanding center in the auditory system. Considering the previous findings on this issue, it is emphasized that more research is needed in this area (Billings et al., 2017; Hall III, 2015; Picton, 2010).

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Table 2. Descriptive statistics of SIN groups.

SIN	Group	Mean±SD
onset ICRA noise +5 dB SNR N1 lat.	1	183,2±18,09
	2	184,8±13,2
onset ICRA noise +10 dB SNR N1 lat.	1	184,4±10,72
	2	184±10,445
onset white noise +5 dB SNR N1 lat.	1	163,2±8,02
	2	164±7,36
onset white noise +10 dB SNR N1 lat.	1	162,66±8,5
	2	157,6±7,5
onset quiet N1 lat.	1	153,6±8,8
	2	155,06±9,2
onset quiet N1-P2 amp.	1	(-5,37)±1,7
	2	(-6,7)±3,5
onset ICRA noise +5 dB SNR N1-P2 amp.	1	(-3,2)±0,9
	2	(-3,5)±1,9
onset ICRA noise +10 dB SNR N1- P2 amp.	1	(-3,8)±1,4
	2	(-3,6)±1,5
onset white noise +5 dB SNR N1-P2 amp.	1	(-4,7)±1,49
	2	(-6,6)±2,7
onset white noise +10 dB SNR N1-P2 amp.	1	(-4,7)±1,49
	2	(-6,6)±2,7
acc ICRA noise +5 dB SNR N1 lat.	1	674,13±28,2
	2	670,53±30,3
acc ICRA noise +10 dB SNR N1 lat.	1	686,66±23,46
	2	669,06±26,5
acc white noise +5 dB SNR N1 lat.	1	680,53±33,5
	2	665,86±34,8
acc white noise +10 dB SNR N1 lat.	1	683,73±33,37
	2	664,93±26,5
acc quiet N1 lat.	1	664±23,6
	2	651,8±22,07
acc ICRA noise +5 dB SNR N1-P2 amp.	1	(-1,5)±1,03
	2	(-1,6)±0.8
acc ICRA noise +10 dB SNR N1-P2 amp.	1	(-1,7)±1,1
	2	(-1,5)±0,
acc white noise +5 dB SNR N1-P2 amp.	1	(-1,5)±0,9
	2	(-1,4)±0,8
acc white noise +10 dB SNR N1-P2 amp.	1	(-1,8)±0,7
	2	(-1,5)±1,6
acc quiet N1-P2 amp.	1	(-2,47)±1,09
	2	(-2,5)±1,03

(latencies are in ms and, amplitudes are in mV)

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Researchers examining the effects of noise on CAEPs stated that the type of noise is as important as the spectral characteristics and periodicity differences of the stimulus presented in the noise. For example, Niemczak and Vander Werff (2019) found that *babble* noise affects the cortical potentials evoked by /ui/ more than the speech shaped noise (SSN). In their study, auditory potentials were recorded in three different noises (8 talker-2 talker *babble* noise and speech-shaped noise) with the /ui/ stimulus. There was a change in wave morphology in each noise type compared to the quiet. Besides, It was observed that *babble* noise consisting of eight talkers (8T) and two talkers (2T) had a greater effect than SSN, there was a greater reduction in N1-P2 amplitudes in *babble* noise (Niemczak & Vander Werff, 2019).

In the present study, ICRA noise and white noise were used, each with different spectral and temporal properties. There was a decrease in the onset sound N1-P2 peak-to-peak response amplitudes in ICRA noise compared to the quiet, but no significant difference for white noise was obtained. In addition, the onset N1 latencies and N1-P2 peak-to-peak amplitudes were obtained higher and lower in ICRA noise than in white noise, respectively. These findings are in line with with the studies of Niemczak and Vander Werff (2019) and Maamor and Billings (2017). In both studies, SSN noise and two separate temporally modulated speech noises were compared with the quiet condition. It has been observed that modulated speech noises resulted in more reductions in N1-P2 amplitudes than continuous speech spectrum noise (Maamor & Billings, 2017; Niemczak & Vander Werff, 2019). It can be concluded that spectraly and temporally modulated noises (ICRA noise in the current study) have more prononunced effect on cortical responses compared to steady noise.

ACC can be considered as an indicator for evaluating speech perception ability. This cortical response to acoustic change in the stimulus indicates that the change in an ongoing signal is detected at the cortical level. In the current study, the effects of noise on sound onset and ACC N1 were investigated by using the /ui/ stimulus, different noise types and different SNRs. In our study, it was observed that ICRA +10 dB SNR and white noise +5 dB SNRs caused a prolongation in ACC N1 latency compared to the quiet. In addition, ACC N1-P2 peak-to-peak amplitudes decreased at ICRA +5 and +10 dB SNR and white noise at +5 SNR compared to quiet. These findings are consistent with previous studies reporting that sound change evoked responses are affected by noise (Ganapathy & Manjula 2016; Niemczak & Vander Werff, 2019; Yaralı, 2020). For example, Ganapathy and Manjula (2016), examining the effect of noise on the ACC and sound onset responses evoked by the consonant-vowel syllable /sa/, found that noise resulted in a prolongation of the ACC and the sound onset response latencies and a decrease in amplitude, and stated that this effect was less for the ACC than the sound onset response (Ganapathy & Manjula 2016). In another study, Yaralı (2020)

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observed that both the sound onset and the ACC response formed by the /ui/ stimulus were affected by noise, and stated that the noise effect was more on the ACC than the sound onset response (Yaralı, 2020).

When sound onset responses were examined in our study, it was observed that each noise type and SNR resulted in sound onset N1 latency prolongations compared to the quiet condition. This finding is in line with studies on the effect of noise on N1 latencies (Billings et al., 2017; McCullagh et al., 2012). Sound onset N1- P2 peak-to-peak amplitudes, similar to N1 latencies, were lower at ICRA +5 dB and +10 dB SNR compared to the quiet. However, white noise did not have a significant effect on amplitudes under any SNR condition compared to the quiet. Considering the sound onset N1, it was observed that each noise type caused prolonged N1 latencies compared to the quiet, but the decrease in the N1-P2 peak-to-peak amplitudes depends on the noise type. This finding is in line with some previous studies. For example, Billings et al. (2011) compared four types of noise and stated that the noise containing speech sound was the noise that prolonged the sound onset N1 latency the most among other noise types. The authors stated that background noise containing speech sounds is a more difficult listening condition (Billings et al., 2011). In the study of Bennett et al. (2012), speech and tonal stimuli were presented under different noise conditions. Behavioral (discrimination and reaction times) and cortical responses (P3 response) to the speech stimuli in the *bable* noise condition were decreased compared to the other conditions (Bennett et al., 2012).

In our study, the finding that the varying signal-noise ratio had no effect on neural responses was found to be compatible with some previous studies (Small et al., 2018; Whiting et al., 1998). It is thought that this finding may be related to the noise level, type and type of stimulus used. Our recommendation for future studies is to examine the effect of noise on neural responses by using different noise levels and stimulus types at different signal-to-noise ratios.

When the neural responses were compared between the groups with different SIN scores, the sound onset N1-P2 amplitudes were higher in the group with low SIN scores only in the +5 dB SNR white noise condition compared to the group with high SIN scores. This finding is in line with with the idea of utilizing more neural resources while processing speech in noise (Anderson et al., 2010). On the other hand, the amplitudes and latencies of cortical potentials were not correlated with SIN scores. It can be thought that this finding is related to the fact that SIN scores did not show much variability among the participants. Investigating cortical potentials in noise in populations with a wider range of SIN scores can be suggested for future studies. Considering the small number of studies on the relationship between behavioral SIN abilities and neural representations of speech sounds in noise, more parameters

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should be evaluated in the future studies on this issue.

An argument may be that the SNRs utilized for behavioral SIN test and evoked potential recording are different, thus effecting the results. Evoked potentials usually show a dramatic decrement at low SNR's, thus making peak detection not reliable. For this reason, relatively higher SNR's were utilized for evoked potential recording. This mismatch may be limitation of the current study and may have affected our results; that is, finding no between group differences may be related to relatively high SNR's in evoked potential recordings. Moreover, although the participant groups were significantly different in behavioral SIN scores, no siginificant difference in evoked potential parameters were observed except for one condition. Another limitation of the study appears at this point, the participants did not have a wide range of SIN scores in behavioral test, thus resulting in non-existing relationship between cortical responses and behavioral SIN scores in the current study.

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Declaration of Conflicting Interest

The authors declare no conflicts of interest.

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