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Assessment of the Speech Intelligibility Performance of Post Lingual Cochlear Implant Users at Different Signal-to-Noise Ratios Using the Turkish Matrix Test

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Background: Spoken word recognition and speech perception tests in quiet are being used as a routine in assessment of the benefit which children and adult cochlear implant users receive from their devices. Cochlear implant users generally demonstrate high level performances in these test materials as they are able to achieve high level speech perception ability in quiet situations. Although these test materials provide valuable information regarding Cochlear Implant (CI) users' performances in optimal listening conditions, they do not give realistic information regarding performances in adverse listening conditions, which is the case in the everyday environment.
Aims: The aim of this study was to assess the speech intelligibility performance of post lingual CI users in the presence of noise at different signal-to-noise ratio with the Matrix Test developed for Turkish language.
Study Design: Cross-sectional study.
Methods: The thirty post lingual implant user adult subjects, who had been using implants for a minimum of one year, were evaluated with Turkish Matrix test. Subjects' speech intelligibility was measured using the adaptive and non-adaptive Matrix Test in quiet and noisy environments.
Results: The results of the study show a correlation between Pure Tone Average (PTA) values of the subjects and Matrix test Speech Reception Threshold (SRT) values in the quiet. Hence, it is possible to asses PTA values of CI users using the Matrix Test also. However, no correlations were found between Matrix SRT values in the quiet and Matrix SRT values in noise. Similarly, the correlation between PTA values and intelligibility scores in noise was also not significant. Therefore, it may not be possible to assess the intelligibility performance of CI users using test batteries performed in quiet conditions.
Conclusion: The Matrix Test can be used to assess the benefit of CI users from their systems in everyday life, since it is possible to perform intelligibility test with the Matrix test using a material that CI users experience in their everyday life and it is possible to assess their difficulty in speech discrimination in noisy conditions they have to cope with.
Keywords: Turkish Matrix Test, noise, speech intelligibility, cochlear implant

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Hearing loss impairs the ability to understand speech in the quiet and it becomes even harder for these individuals to understand speech in the presence of background noise (1). It is possible for this situation to be overcome to some extent by using hearing aids. In the case of patients with severe to profound hearing loss, since they can obtain little benefit from hearing aids, the solution may be cochlear implant (CI).

Spoken word recognition and speech perception tests in the quiet are being used as a routine in the assessment of benefits which children and adult cochlear implant users receive from their devices. Cochlear implant users generally demonstrate high level performances in these test materials as they are able to achieve high level speech perception ability in the quiet. Although these test materials give valuable information regarding CI users' performances in optimal listening conditions, they do not give realistic information regarding performances in adverse listening conditions which is the case in the everyday environment (2).

Techniques such as directional microphones and adaptive noise reduction systems are implemented in cochlear implants (3). By means of the implementation of these techniques, CI users' speech recognition scores in the quiet might be higher; however, their speech recognition scores in noisy conditions are still not quite as competent (4). Factors such as fine spectral and temporal information and the narrow dynamic range in electrical stimulation, mainly relating to the limitations in the hardware and software of devices, are the reasons for poor speech perception in conditions of noise (4,5).

Speech intelligibility evaluation in adverse conditions resembling those of everyday environments, such as the presence of background noise at different signal-to-noise ratios, is of particular importance (6). Using sentences is advantageous over the use of single words, in terms of giving more accurate estimated speech reception threshold values while resulting in steeper slopes of psychometric function curves (7) speech intelligibility tests can be used for evaluating speech intelligibility in realistic rooms like offices, classrooms or auditoriums. Therefore, well standardized speech intelligibility tests and methods which are comparable across languages are needed. The current work presents a evaluation procedure and the preliminary results of normally hearing listeners of the newly developed Italian Matrix Sentence Test for assessing speech reception thresholds (SRT, i.e. signalto-noise ratio SNR of 50% intelligibility.

The Matrix test is one of the sentence recognition in noise tests, such as SPIN and HINT. This test was developed by Hagerman in 1982 for Swedish (8). The Turkish version of the test was first introduced by Zokoll et al. (9) and it is present today for a number of other languages (German, Danish, British English, Polish, French, Russian, Spanish, American English, Dutch) including Turkish (10). The Turkish version of the Matrix test was normalized and used for the assessment of speech intelligibility of normal hearing Turkish subjects by Zokoll et al. (11).

The aim of our study was to assess the speech intelligibility performance of post lingual CI users in the presence of noise at different signal-to-noise ratios with the Matrix test developed for Turkish language.

MATERIALS AND METHODS

This work was designed and conducted in accordance with the ethical standards of the Helsinki Declaration. Approval was given for this work by the Institutional Ethics Committee. A detailed explanation of the procedures that they may undergo was given to the subjects and a signed informed consent form was obtained from each participant.

Subjects

Thirty CI users (14 males, 16 females) participated in this study. The subjects were adults between the ages of 20 and 66. The average age was 44 and the standard deviation was 14 years. The mean length of hearing loss was 19 years and the standard deviation was 8 years. During the time of measurements, the subjects had been using their CI for a minimum of 1 year, with a mean experience of 5.38 +/- 4.98 years.

Eighteen subjects had an Opus2™ sound processor (Med-El™; Innsbruck, Austria), 7 subjects had Nucleus 6 processor (Cochlear™; North Sydney, Australia) and 5 subjects had a Naida CI Q70 processor (AB™; Zurich, Switzerland) device. All sound processors used in this study were Behind the Ear (BTE) type.

All subjects, except for one case, had post lingual hearing loss and were unilateral CI users. The prelingual case had bilateral CI. This user was tested unilaterally in the better ear. All subjects had been using a hearing aid for the duration of their hearing loss. Pure tone audiometry and speech audiometry test batteries were applied to all subjects.

Subjects with a speech discrimination score (SDS) lower than 60% with CI were not included in the study.

The characteristics of the group are given in Table 1. The Turkish Matrix test was used for the measurement of the speech intelligibility score in quiet and noise. Before the measurements, two training sessions (one time in quiet and one times in noise) were performed for all subjects, as recommended by Wagener et al. (12).

Measurement setup

Subjects were seated in the middle of two speakers, facing the front speaker in a double-walled sound chamber. The

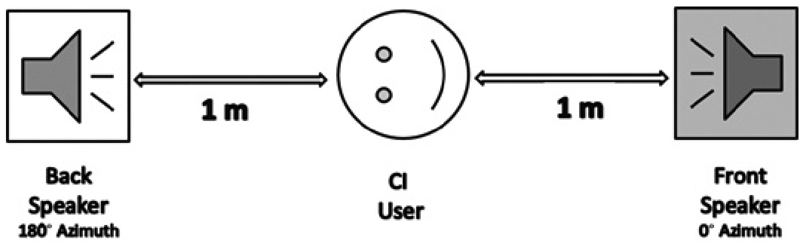

FIG. 1. Measurement setup

TABLE 1. The characteristics of the group.

Case No	Age (year)	Gender	Length of CI Use (year)	Length of HL (year)	CI Side
1	35	M	2	15	Right Ear
2	35	F	2	19	Right Ear
3	44	F	1	34	Right Ear
4	21	F	2	21	Right Ear
5	44	F	1	30	Right Ear
6	25	F	2	17	Right Ear
7	48	M	1	30	Right Ear
8	45	F	5	11	Right Ear
9	23	M	3	16	Right Ear
10	56	M	4	32	Right Ear
11	38	F	3	24	Right Ear
12	30	F	4	25	Right Ear
13	51	M	2	22	Right Ear
14	64	F	1	30	Right Ear
15	42	M	1	24	Right Ear
16	60	M	4	6	Left Ear
17	29	M	15	16	Left Ear
18	58	F	14	19	Right Ear
19	43	F	3	10	Right Ear
20	52	M	15	30	Right Ear
21	53	M	9	15	Left Ear
22	56	M	20	30	Right Ear
23	51	F	2	8	Right Ear
24	66	F	4	15	Left Ear
25	26	F	11	12	Left Ear
26	38	F	7	17	Right Ear
27	59	M	6	12	Right Ear
28	39	M	3	10	Right Ear
29	20	M	9	20	Right Ear
30	65	K	5	13	Right Ear

CI: cochlear implant; HL: hearing Loss; M: male; F: female

other speaker was behind the subjects at an azimuth of 180 degrees. In this study, an audiometer (AURICAL Aud, Otometrics; Taastrup, Denmark) with approval for use with the "Oldenburg Measurement Applications (HörTech; Oldenburg, Germany)" software was used. The measurement set up is shown in Figure 1.

Before the subjects took the Turkish Matrix test, their hearing threshold levels were determined with CI in a free field. The Speech Reception Thresholds (SRT) of the subjects were tested by Turkish polysyllabic words while their Speech Discrimination Scores (SDS) were tested in the most comfortable level by list of 25 monosyllabic words in the quiet.

Also, all subjects' speech intelligibility was measured using the Turkish Adaptive and Non-Adaptive Matrix Test in quiet and noisy conditions. The test battery consists of 20 sentence test lists. A bubble noise was used to measure the subjects' speech intelligibility during noise. The noise was adjusted to continuous mode and its level was 65 dB SPL.

In each session of the Turkish Matrix Test measurement, the following measurements given in Table 2 were conducted. All of the tests were performed unilaterally and the subjects used only their CIs in the tested ear during the test. The subjects were allowed breaks if they needed.

Statistical analysis

Statistical analysis was performed using Statistical Package for Social Sciences (SPSS) 20.0 for Windows (IBM Corporation; New York, USA). Mann-Whitney U test was used to determine the significance of differences between the measurements taken when noise was in front and when noise was in the rear. Spearman's rho test was used to make a correlations analysis. The value of $p \leq 0.05$ was considered to be significant.

RESULTS

The pure tone thresholds were measured and the pure tone average (PTA) values were calculated for each subject in the free field for 500, 1000, 2000, and 4000 Hz. The minimum, maximum and average values are shown in Figure 2.

Table 3 shows minimum, maximum, mean and standard deviation values of both pure tone and Matrix Test measurements. In the table, the PTA values are given in dB HL scale and the Adaptive Matrix SRT in Quiet values are in dB SPL. Adaptive Matrix SRT in Noise values shows a ratio of signal and noise presented to the subjects, hence they are in dB SNR scale. The performances of the subjects in the Non-Adaptive Intelligibility Score Test are obtained as the percentage of the correct responses; therefore, they are given in percent (%) scale in the Table.

Figure 3 shows the mean speech intelligibility scores of the subjects for different S/N Ratio and noise presentation conditions. The black bars show the values obtained when speech was presented from 0 degrees (front) and noise was presented from -180 degrees (rear). The measurement values when both

TABLE 2. Measurements conducted for each subject

No	Measurement	S/N Ratio (dB)	
1	Adaptive Matrix SRT in quiet		
2	Adaptive Matrix SRT in Noise		Noise in front
3	Adaptive Matrix SRT in Noise		Noise in rear
4	Non-adaptive Intelligibility Score in Quiet (65 dB SPL)		
5	Non-adaptive Intelligibility Score in Noise	-10	Noise in front
6	Non-adaptive Intelligibility Score in Noise	-5	Noise in front
7	Non-adaptive Intelligibility Score in Noise	0	Noise in front
8	Non-adaptive Intelligibility Score in Noise	5	Noise in front
9	Non-adaptive Intelligibility Score in Noise	10	Noise in front
10	Non-adaptive Intelligibility Score in Noise	-10	Noise in rear
11	Non-adaptive Intelligibility Score in Noise	-5	Noise in rear
12	Non-adaptive Intelligibility Score in Noise	0	Noise in rear
13	Non-adaptive Intelligibility Score in Noise	+5	Noise in rear
14	Non-adaptive Intelligibility Score in Noise	+10	Noise in rear

SRT: speech reception threshold; dB: decibel; SPL: sound pressure level; S/N Ratio: signal to noise ratio

TABLE 3. Descriptive statistics of measurements

	S/N ratio	Speech	Noise	Mean+/-SD
PTA	-	Front		22.46+/-3.74
Adaptive Matrix SRT in Quiet	-	Front	-	43.98+/-6.39
Adaptive Matrix SRT in Noise	-	Front	Front	-.62+/-2.11
Adaptive Matrix SRT in Noise	-	Front	Rear	-4.90+/-3.47
Non-adaptive Intelligibility Score in Quiet	-	Front	-	91.10+/-5.59
Non-adaptive Intelligibility Score in Noise	-10	Front	Front	2.30+/-4.80
Non-adaptive Intelligibility Score in Noise	-5	Front	Front	30.23+/-20.26
Non-adaptive Intelligibility Score in Noise	0	Front	Front	74.37+/-13.09
Non-adaptive Intelligibility Score in Noise	+5	Front	Front	89.30+/-8.53
Non-adaptive Intelligibility Score in Noise	+10	Front	Front	94.00+/-6.28
Non-adaptive Intelligibility Score in Noise	-10	Front	Rear	37.37+/-28.29
Non-adaptive Intelligibility Score in Noise	-5	Front	Rear	68.20+/-27.24
Non-adaptive Intelligibility Score in Noise	0	Front	Rear	86.90+/-11.67
Non-adaptive Intelligibility Score in Noise	+5	Front	Rear	93.19+/-7.86
Non-adaptive Intelligibility Score in Noise	+10	Front	Rear	96.67+/-4.64

PTA: pure ton average; SRT: speech reception threshold; S/N Ratio: signal to noise ratio; Min: minimum; Max: maximum; SD: standard deviation

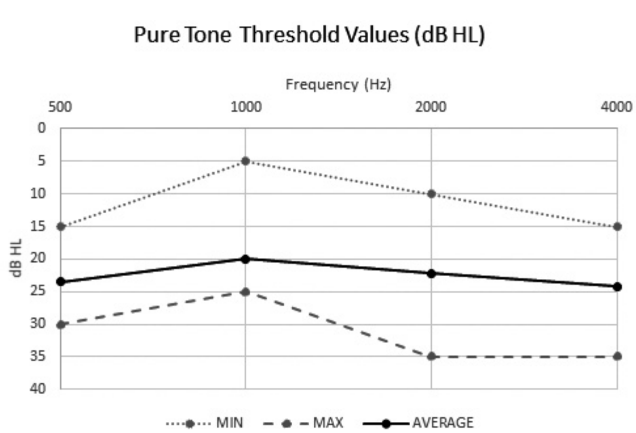

FIG. 2. Pure tone thresholds values of subjects

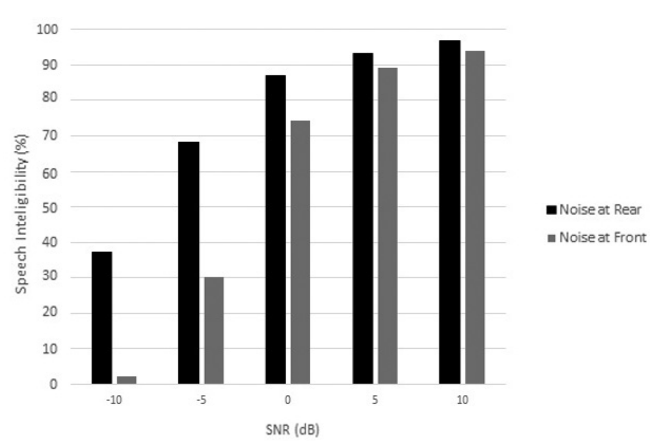

FIG. 3. Mean speech intelligibility scores of subjects for different S/N Ratios

speech and noise were presented from 0 degrees (front) are shown as gray bars. As shown from the figure, the performance gap between the two conditions was increased as the SNR value decreased.

The difference between the performances obtained in different noise presentation directions was analyzed using the Mann-Whitney U test; the results are shown in Table 4. As seen from the Table, the intelligibility scores obtained at -10 dB, -5 dB, 0 dB and +5 dB SNR when noise was presented from the rear were found to be significantly different from the values when noise was presented from the front direction ($p<0.05$). As the SNR value increased, the performances were the same in both conditions and statistically significant differences were not found for +10dB SNR. Adaptive Matrix SRT in Noise values were also obtained different for front and rear noise presentation conditions; this difference was also found to be statistically significant ($p<0.05$).

A spearman correlation analysis was performed to determine the effects of PTA values on Matrix test performances. As seen from the results in Table 5, the PTA values are related to the performances in Turkish Matrix Test for quiet conditions. However, there is no a statistically significant correlation between the results obtained in noisy conditions and the PTA values.

The correlations between adaptive and non-adaptive tests were also calculated using SPSS. Statistical analysis did not reveal any significant correlation between Adaptive Matrix SRT values in noise and Intelligibility Scores in the quiet ($p>0.05$). However, there is a correlation between the non-adaptive intelligibility score in quiet and adaptive matrix SRT in quiet values (rho=-0.674, $p<0.05$). The correlation coefficient is negative, as expected.

TABLE 4. Measurements conducted for each subject

	p
Adaptive Matrix SRT in Noise	0.000
Non-adaptive Intelligibility Score in Noise S/N Ratio -10dB	0.000
Non-adaptive Intelligibility Score in Noise S/N Ratio -5 dB	0.000
Non-adaptive Intelligibility Score in Noise S/N Ratio 0 dB	0.000
Non-adaptive Intelligibility Score in Noise S/N Ratio +5 dB	0.025
Non-adaptive Intelligibility Score in Noise S/N Ratio +10 dB	0.064

SRT: speech reception threshold; S/N Ratio: signal to noise ratio; dB: decibel

DISCUSSION

The aim of this study was to determine the speech intelligibility performances of post lingual CI users in the presence of noise at different signal-to-noise ratios with the Matrix test developed for Turkish language.

Advantage of the directivity of cochlear implant

As shown in Figure 3, there was a performance gap between the conditions when noise was presented from the front and when noise was presented from the rear; this gap was increased as the SNR value decreased. As seen from Table 4, the intelligibility scores obtained at -10 dB, -5 dB, 0 dB and +5 dB SNR when noise was presented from the rear were found to be significantly different from the values when noise was presented from the front ($p<0.05$). However, statistically significant differences were not found for +10dB SNR.

Cochlear Implant users have to deal with noisy situations in everyday life and they mostly encounter low SNR values. These results show that the difficulty experienced by subjects in noise increases with decreasing SNR values. Directionality of hearing may increase their performance in noisy situations if noise is presented from the rear. The intelligibility performance was not affected by the direction of the presented noise at high SNR values, as expected.

Similar results were also found in the literature. Wimmer et al. (13) measured the speech intelligibility in noise performance of experienced CI users in 4 spatial configuration with the Oldenburg sentence test. They compared the SRT performance between Rondo and Opus 2 system and found no statistically significant differences in the situations in which the signal came from the front and noise came from the frontal, ipsilateral and contralateral sides. However, they found 4.4 dB better SRT with Opus 2 compared to Rondo in the case of noise presented from the back. They concluded that CI users with the receiver/stimulator implanted in positions further behind the ear were expected to have greater difficulties in noisy situations when

TABLE 5. Spearman correlation analysis of PTA and Matrix Test results

		Adaptive Matrix SRT in Noise (Noise at Front)	Adaptive Matrix SRT in Noise (Noise at Rear)	Adaptive Matrix SRT in Quiet	Non-adaptive Intelligibility Score in Quiet
PTA	Correlation Coefficient	0.059	0.243	0.620	-0.632
	Sig. (2-tailed)	0.759	0.196	0.000	0.000

PTA: pure tone average; SRT: speech reception threshold; Sig.: significance level wearing a Rondo processor. Because the Opus 2 system has a microphone placed in front of the pinna, users have an advantage of shadowing effects of the pinna when noise is presented from behind. They also suggested that multi-microphone noise reduction techniques might be more beneficial.

Similarly, Wimmer et al. (4) compared the speech intelligibility scores of CI users equipped with Sonnet system and Opus 2 system. They did not observe a significant difference between the Opus 2 system and the Sonnet in the omnidirectional mode. However, they measured 3.6 dB better SRT values with the Sonnet system in directional mode when the noise came from the back and the speech came from the front. They concluded that the directionality of the Sonnet system might help CI users to increase recognition performance when speech and noise were presented from different directions.

The results of this study are also similar to those in the literature. Adaptive Matrix SRT in Noise values measured in the situations in which noise and speech came from the front were 4.28 dB worse than the values obtained in the conditions when noise came from the back.

Since the Opus 2 sound processor has a microphone placed in front of the pinna, the users had an advantage of shadowing effects of the pinna when noise presented from behind. The Nucleus 6 processor and the Naida CI Q70 processor have dual microphones and were adjusted in the directional mode. Therefore, the users had the advantage of a directional microphone.

The relationship between PTA and MATRIX test scores

In our study, a relationship between PTA and the performance values of the Matrix test in the quiet was found. As seen from the results given in Table 5, the PTA values are related to the values of Adaptive Matrix SRT in Quiet. The correlation coefficient was found to be 0.620 and this correlation was statistically significant ($p<0.05$).

Similar results were found in the literature. Zokoll et al. (11) conducted a normalization study in normal hearing subjects for the Turkish Matrix test and also measured the adaptive SRT value in the quiet, while calculating the correlation coefficient between PTA values and SRT values in the quiet. The correlation coefficient was found to be 0.623. They stated that this correlation was statistically significant ($p<0.05$).

Also, there was a relationship between PTA values of subjects and the Non-adaptive Intelligibility Scores in Quiet. As expected, a negative correlation coefficient was found. This correlation was also statistically significant ($p<0.05$). However, there is no statistically significant correlation between the PTA values and Adaptive Matrix SRT in Noise (Noise at front or rear) ($p>0.05$).

Comparison between normal hearing subjects and CI users

In this study, Adaptive Matrix SRT in Noise when the noise was in front was found to be -0.62 +/- 2.11 dB SNR and when the noise was in the rear was found to be -4.90 +/- 3.47 dB SNR. Although a similar study for Turkish CI users could not be found, Zokoll et al. (11) measured the intelligibility scores at fixed SNRs in normal hearing subjects using the Turkish Matrix test. Then they calculated the mean SRT value of subjects and found that the subjects has a speech intelligibility score of 50% at -8.3 +/- 0.2 dB SNR. However, Kollmeier et al. (8) reported that the SRT values obtained from measurements directly using adaptive algorithm in the Turkish Matrix test were -7.2 +/- 0.8 dB SNR in normal hearing subjects. As seen from the results of both studies, Turkish CI users had a worse performance in noise than normal hearing subjects.

Similar performance degradations were also reported in the literature. Hey et al. (14) reported that German CI users had a mean SRT value of -2 dB SNR measured using the adaptive test in noise algorithm given in the German matrix test. However, Kollmeier et al. (8) reported that German normal hearing subjects had -6.8 dB SNR measured with the same algorithm. This means that CI users had 4.8 dB worse SRT values. Similar results were also reported by Dietz et al. (15) for the Finnish Matrix test. They reported the mean SRT values for CI users to be -3.5 dB SNR and for normal hearing subjects to be -9.7 dB SNR. That means that 6.2 dB worse SRT values were obtained for the Finnish CI users group.

Relationship between adaptive and non-adaptive algorithms

Statistical analysis did not reveal any significant correlation between Adaptive Matrix SRT values in noise and Non-adaptive Intelligibility Scores in the quiet ($p>0.05$). However there is a correlation between the Non-adaptive Intelligibility Score in Quiet and the Adaptive Matrix SRT in Quiet values ($p<0.05$). Similarly, Zokoll et al. (11) did not report any significant correlation between SRT in quiet (dB SPL) and adaptive SRT in noise (dB SNR).

The results of the study shows a correlation between PTA values of the subjects and Matrix test SRT values in the quiet. Hence, it is possible to assess the PTA values of CI users using the Matrix Test also. However, no correlations were found between Matrix SRT values in the quiet and Matrix SRT values in noisy conditions. Similarly, the correlation between PTA values and intelligibility scores in noise was also not significant. Therefore, it may not be possible to assess the intelligibility performance of CI users using test batteries performed in quiet conditions. There are some other methods used to test the hearing performance in noise such as the Turkish HINT test. However, some advantages of the Turkish Matrix test reported in the literature show that it has better efficiency in testing hearing performance in noise (11). It could be concluded that the Matrix Test can be used to assess the benefits that CI users gain from their systems in everyday life, since with the Matrix test it is possible to perform intelligibility tests with a material that CI users use in their everyday life and it is possible to assess their difficulty in speech discrimination in noisy conditions which they have to cope.

Ethics Committee Approval: Ethics committee approval was received for this study from institutional ethics committee**.**

Informed Consent: Written informed consent was obtained from patients who participated in this study.

Peer-review: Externally peer-reviewed.

Author contributions: Concept - Z.P., A.A.; Design - Z.P.; Supervision - A.A.; Resource - Z.P., E.B.; Materials - Z.P., E.B.; Data Collection and/or Processing - Z.P., E.B.; Analysis and/or Interpretation - Z.P., E.B.; Literature Search - Z.P., E.B.; Writing - Z.P.; Critical Reviews - Z.P., A.A., E.B.

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