Korean Clear Speech Improves Speech Intelligibility for Individuals with Normal Hearing and Individuals with Hearing Loss

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Abstract

Background Clear speech is an effective communication strategy to improve speech intelligibility. While clear speech in several languages has been shown to significantly benefit intelligibility among listeners with differential hearing sensitivities and across environments of different noise levels, whether these results apply to Korean clear speech is unclear on account of the language's unique acoustic and linguistic characteristics.

Purpose This study aimed to measure the intelligibility benefits of Korean clear speech relative to those of conversational speech among listeners with normal hearing and hearing loss.

Research Design We used a mixed-model design that included both within-subject (effects of speaking style and listening condition) and between-subject (hearing status) elements.

Data Collection and Analysis We compared the rationalized arcsine unit scores, which were transformed from the number of keywords recognized and repeated, between clear and conversational speech in groups with different hearing sensitivities across five listening conditions (quiet and 10, 5, 0, and −5 dB signal-to-noise ratio) using a mixed model analysis.

Results The intelligibility scores of Korean clear speech were significantly higher than those of conversational speech under most listening conditions in all groups; the former yielded increases of 6 to 32 rationalized arcsine units in intelligibility.

Conclusion The present study provides information on the actual benefits of Korean clear speech for listeners with varying hearing sensitivities. Audiologists or hearing professionals may use this information to establish communication strategies for Korean patients with hearing loss.

Keywords
- speech perception
- clear speech
- communication strategy

Conversational speech is the natural manner of speaking used in daily life. However, sometimes individuals naturally produce clear speech in situations where successful communication must overcome challenges such as background noise or a listener who has hearing difficulties. Clear speech is considered a communication strategy by which speech intelligibility can be improved; indeed, research on English clear speech has reported that it facilitates intelligibility for people with hearing loss, those with normal hearing (NH) regardless of age, and in noisy environments.[1–5] The benefits of clear speech have also

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been reported in other languages, such as Croatian[4] and Telugu.[6]

Clear speech has several acoustic characteristics that account for its enhanced speech intelligibility relative to conversational speech, such as slower speech rate.[7–9] Smiljanic and Gilbert[8] reported that English clear speech is typically 1.2 to 1.4 times slower than conversational speech. Vowel modifications have also been reported in studies between clear and conversational speech.[1,10] Ferguson and Kewley-Port[10] found that vowel space expansion and vowel duration increase in English clear speech were associated with improved vowel intelligibility compared with conversational speech. Further, other characteristics of clear speech, such as a wider fundamental frequency range, increased temporal envelope modulation, and increased pause rate, are reportedly relevant to the superior intelligibility or clarity of this communication strategy.[8,11,12] The aforementioned findings indicate that several acoustic characteristics of clear speech may contribute to its facilitation of speech intelligibility when compared with conversational speech.

This study considered the benefits of clear speech in the comprehension of Korean, whose linguistic characteristics differ from those of English. There are a few studies that identify how various acoustic characteristics of Korean clear speech differ from those of conversational speech.[13,14] Similar to English clear speech, Korean clear speech is produced more slowly than conversational speech at rates as slow as 35 to 45% of the speed of conversational speech.[14] Further, Cho et al[13] demonstrated that Korean clear speech is approximately 1.4 times slower than conversational speech (syllables per second). However, some features of Korean clear speech differ from English clear speech.[13] For example, a review of clear speech studies conducted by Smiljanic and Bradlow[15] revealed that several studies indicate that English clear speech consistently results in pitch range expansion. However, no such pattern has been observed in Korean clear speech.[13] The results of previous studies indicate that there are similarities and differences in the acoustic characteristics between Korean and English clear speech. Although there is evidence supporting the intelligibility benefits of English clear speech, it remains unclear whether a similar degree of intelligibility benefit exists for Korean clear speech, given different acoustic features of clear speech between the two languages. To identify the degree to which Korean clear speech is more intelligible than Korean conversational speech, the intelligibility performances of the two manners of speaking must be measured and compared.

This study also investigates the intelligibility benefits of Korean clear speech not only for listeners with NH but also for listeners with hearing loss. Speech intelligibility performance depends on hearing sensitivity which may affect audibility, dynamic range, ability for speech cue detection and discrimination, etc.[15–17] Generally, as hearing sensitivity worsens, speech intelligibility performance may worsen. In several English clear speech studies, intelligibility benefits of clear speech between listeners with NH and listeners with hearing loss have been compared.[2,18,19] Payton et al[19] report the benefit of clear speech for listeners with NH to be around 20% and that for listeners with severe flat type hearing loss to be approximately 26%. However, Ferguson[2] reported that similar intelligibility benefits for clear speech were observed between listeners with NH[18] and listeners with mild-to-moderately severe sloping hearing loss in vowel intelligibility conditions. Although the results of previous studies do not clearly explain the benefits of clear speech according to the degree of hearing loss, they do suggest the possibility that the benefit of clear speech may vary depending upon the degree of hearing loss. Thus, there is clinical utility in the investigation of the benefits of Korean clear speech in groups with various hearing sensitivity, rather than only one group.

Hence, this study aimed to identify the intelligibility benefits of Korean clear speech for listeners with different hearing sensitivity conditions. We hypothesized that Korean clear speech would differentially benefit listeners according to their respective levels of hearing sensitivity. The results of the present study should elucidate the degree of benefits for Korean clear speech across listeners with various hearing sensitivities.

Methods

Listeners

We enrolled 150 listeners and subsequently sorted them into three groups to investigate the intelligibility of Korean clear speech: 50 young adults with NH (18 men; mean age, 24.4 years; age range, 20–29 years), 50 older adults with mild-to-moderate sloping hearing loss (less hearing loss [LHL]; 20 men; mean age, 74.8 years; age range, 65–85 year), and 50 older adults with moderate-to-severe sloping hearing loss (more hearing loss [MHL]; 31 men; mean age, 74.9 years; age range, 65–89 years). All listeners were native speakers of Korean.

Auditory thresholds and word recognition scores (WRSs) for all listeners were assessed as per standards established by our laboratory. For each ear, both tests were measured in a double-walled, sound-attenuated booth using an audiometer (GSI61, Grason-Stadler, Eden Prairie, MN) through a headphone (TDH-50p, Telephonics Corporation, Farmingdale, NY). For auditory thresholds, pure-tones from 250 to 8,000 Hz were used as stimuli. For the WRS, recorded voices of standardized Korean monosyllabic word lists for adults were used and each list consisted of 50 words.[20] ►Fig. 1 represents the averaged

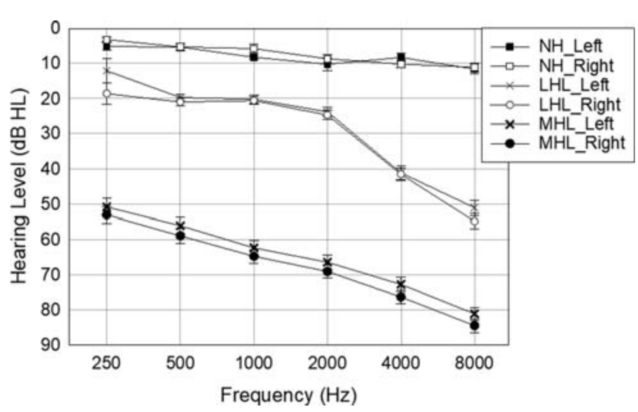

Fig. 1 Averaged hearing thresholds with standard errors for groups with normal hearing (NH), less hearing loss (LHL), and more hearing loss (MHL) as a function of the octave frequency bands.

hearing thresholds as a function of octave band frequency for NH, LHL, and MHL groups. The auditory thresholds of all listeners in the NH group were 15 dB hearing level (HL) or better, with octave frequencies from 250 to 8,000 Hz.[21] The NH listeners achieved WRSs of 90% or better.

The LHL group showed mild-to-moderate sloping hearing loss. Ranges of hearing thresholds of listeners at octave frequencies from 250 to 8,000 Hz were between 5 and 30, 15 and 30, 15 and 35, 15 and 40, 25 and 50, and 35 and 60 dB HL. The WRSs of all LHL listeners were 80% or better. No listeners used hearing aids or other assistive listening devices. Because cognitive function may affect the comprehension of speech in older listeners, the presence of cognitive problems was used as an exclusion criterion. The Korean version of the Mini-Mental State Examination (K-MMSE) was used to evaluate cognitive function[22]: the assessment consists of 19 items that total to a maximum score of 30 (10 points for orientation, 6 for verbal memory, 5 for language, 5 for concentration and calculation, 3 for praxis, and 1 for visuospatial construction). Although the criteria for normal cognitive function ("no cognitive impairment") depend on various factors such as age, education level, and sex, a score of at least 24 points indicates that cognitive function is normal regardless of these factors. All listeners who were older adults (the LHL and MHL groups) in the current study achieved K-MMSE scores of ≥ 25.

The MHL group showed moderate-to-severe sloping hearing loss. Ranges of hearing thresholds of listeners at octave frequencies from 250 to 8,000 Hz were between 40 and 65, 40 and 70, 45 and 75, 50 and 75, 55 and 80, and 65 and 90 dB HL. The average WRSs of MHL listeners were 64.9% (standard deviation [SD], 18.3; standard error [SE], 2.6) for the left ear and 63.0% (SD: 21.2, SE: 3.0) for the right ear. The MHL listeners used hearing aids (21 for unilateral users and 29 for bilateral users).

Stimuli

To measure speech intelligibility in clear and conversational speech, sentences from the Hearing-In-Noise Test for Korean (K-HINT) were used as stimuli.[23] The K-HINT consists of 24 lists with 10 sentences; each sentence includes 3 to 4 keywords. To capture the effect of talker variability, stimuli were recorded by 10 speakers (five men) without hearing or speech production problems. All recordings were made in a double-walled, sound-attenuated booth, and all stimuli were recorded using computerized speech laboratory equipment (KayPENTAX, CSL, Montvale, NJ) with an e-835s microphone (Sennheiser, Wedemark, Germany). Both clear and conversational speech samples were vocalized at a distance of 10 cm from the mouth of the microphone while the subject was sitting in a chair. To obtain the stimuli for conversational speech, speakers were first instructed to read as if they were speaking to a friend. Second, to obtain the stimuli for clear speech, the speakers were instructed to read sentences "while speaking clearly," allowing speakers to determine what this meant; this was undertaken in the same manner as that described in reports of English clear speech.[24]

Consistent with previous research of clear speech,[24] amplitude equalizing of the average root-mean-square (RMS) level for all stimuli was conducted using Adobe Audition (Version 2014.2; Adobe Systems Complex, San Jose, CA) after all the recordings of stimuli were obtained to prevent amplitude differences among speakers. The total number of test conditions were 10 (2 speaking styles $\times$ 5 listening conditions) and each test condition was composed of 20 sentences. The sentences in each test condition were evenly composed of the 10 speaker stimuli (2 sentences per speaker). No sentences were repeated for a given listener.

To test speech intelligibility in various noise conditions, we employed five listening conditions (quiet and 10, 5, 0, and –5 dB signal-to-noise ratio [SNR]). Stimuli were mixed with multitalker babble in a method similar to that of Lam and Tjaden.[24] Multitalker babble produced by 16 people (eight women) was sampled at 44,100 Hz and low-pass filtered at 11,000 Hz. Averaged RMS levels of the multitalker babble were then matched to the levels of speech stimuli, which were concatenated without any separating pauses and digitized at a sampling rate of 44,100 Hz in a low-pass filter of 11,000 Hz using Adobe Audition. To generate five listening conditions, the averaged RMS levels of the multitalker babble were adjusted by using Adobe Audition. Clean speech stimuli (quiet) and stimuli with four SNR conditions in 5 dB steps were generated as compact discs.

Procedure

The stimuli were routed to an audiometer (GSI61, Grason-Stadler) and presented to both of the listener's ears through a free-field speaker (GSI loudspeaker, Grason-Stadler). The output level (70 dB sound pressure level) of the free-field speaker was calibrated using a 1-kHz pure-tone with the same average RMS level of the clean speech stimuli (quiet).

To identify the benefits of clear speech of the three groups under the five listening conditions and emulate daily-life situations as accurately as possible, speech intelligibility tests were conducted in a sound-field condition: each listener was seated in a sound booth at a distance of 1 m from a free-field speaker. Listeners listened to the speech stimuli over the free-field speaker. The listeners were asked to listen to a sentence and then repeat as much of the sentence as possible. Each listener participated in the 10 test conditions (2 speaking styles $\times$ 5 listening conditions) in random order. Then, intelligibility scores were measured by the number of correct keywords per each talker in each test condition. In each test condition, the number of keywords per each talker was between 6 and 8 (total number of keywords of 2 sentences) and the total number of keywords was between 68 and 72 (20 sentences). The number of observation points for each listener was 100 (10 talkers $\times$ 2 speaking styles $\times$ 5 listening conditions) and the total number of observation points was 15,000 (50 listeners in each group $\times$ 3 groups).

In the case of the MHL group, listeners wore their hearing aids during the intelligibility tasks to reflect their real-life environment; for this same reason, hearing aids were fitted according to the habitual use of the listeners.

Data Analysis

To identify significant effects of intelligibility scores according to the speaking style (within-subjects: clear vs. conversational speech), listening condition (within-subjects: quiet and 10, 5, 0, and −5 dB SNR), hearing sensitivity of listeners (between-subjects: NH, LHL, and MHL), and their interactions, a generalized linear mixed model (GLMM) analysis was performed. First, the number of correct keywords was converted to a rationalized arcsine unit (RAU) to make them suitable for parametric statistical analysis.[25] However, the RAU data failed the test for normality (Kolmogorov–Smirnov test, statistic: 0.245, $p < 0.001$). Therefore, we used a GLMM analysis which is a statistical method that is appropriate for nonnormal distributions. In addition, the intelligibility scores for the present study were measured by 10 talkers. Thus, the "talker variable" was considered as a random factor in the GLMM analysis.

Results

Averaged RAU scores with SDs calculated according to speaking styles, groups with different hearing sensitivities, and listening conditions are shown in ►**Table 1**. Comparison among groups revealed that hearing sensitivity significantly affected the degree of speech intelligibility ($F = 6778.964$, $p < 0.001$): overall, the better the hearing sensitivity of the listeners, the higher the intelligibility score. For example, in the 5 dB SNR condition, averaged RAU scores for NH, LHL, and MHL groups were 103.21, 87.69, and 21.63 in clear speech condition and 95.22, 76.63, and 13.88 in conversational speech condition, respectively. Comparisons between the listening conditions demonstrated that the listening condition significantly affected speech intelligibility ($F = 9367.604$, $p < 0.001$): overall, intelligibility scores increased as noise decreased. For example, among the LHL group, averaged RAU scores increased from −6.11 to 105.35 in clear speech condition and from −6.16 to 105.02 in conversational speech condition as noise decreased from −5 dB SNR to quiet condition. The comparison between the speaking styles indicated that intelligibility scores were significantly higher in response to clear speech than to conversational speech ($F = 589.900$, $p < 0.001$). For example, in a 10-dB SNR condition, intelligibility benefits for clear speech were 7.36 RAU (102.17 RAU − 94.81 RAU) for LHL group and 32.73 RAU (61.37 RAU − 28.64 RAU) for the MHL group.

There were significant two-way interactions between hearing sensitivity groups and listening conditions ($F = 566.312$, $p < 0.001$), between hearing sensitivity groups and speaking styles ($F = 31.536$, $p < 0.001$), and between listening conditions and speaking styles ($F = 61.448$, $p < 0.001$) on speech intelligibility scores. There was a significant three-way interaction between hearing sensitivity groups, listening conditions, and speaking styles on speech intelligibility scores ($F = 49.084$, $p < 0.001$). In the NH group, clear speech benefits (RAU for clear speech − RAU for conversational speech) were 16.50 RAU (0 dB SNR), 7.99 RAU (5 dB SNR), 6.05 RAU (−5 dB SNR), 2.80 RAU (10 dB SNR), and 0.07 RAU (quiet). The averaged clear speech benefit across all listening conditions was 6.68 RAU. In the LHL group, clear speech benefits were 25.14 RAU (0 dB SNR), 11.06 RAU (5 dB SNR), 7.36 RAU (10 dB SNR), 0.33 RAU (quiet), and 0.05 RAU (−5 dB SNR). The averaged clear speech benefit across all listening conditions was 8.78 RAU. In the MHL group, the differences were 32.73 RAU (10 dB SNR), 8.47 RAU (quiet), 8.11 RAU (0 dB SNR), 7.75 RAU (5 dB SNR), and 0.25 RAU (−5 dB SNR). The averaged clear speech benefit

Table 1 Averaged RAU scores with standard deviations (SDs) for clear speech (CL) and conversational speech (CONV) in the three groups (normal hearing, NH; less hearing loss, LHL; more hearing loss, MHL) as a function of the listening condition (quiet and four dB SNR conditions)

Group	SNR (dB)	Speaking style (RAU)			
		CL		CONV	
		Average	SD	Average	SD
NH	Quiet	105.06	8.54	104.99	8.87
	10	105.90	6.44	103.10	8.23
	5	103.21	8.75	95.22	9.03
	0	86.01	14.39	69.51	11.93
	−5	10.57	15.10	4.52	11.19
LHL	Quiet	105.35	4.69	105.02	5.87
	10	102.17	12.14	94.81	18.85
	5	87.69	11.44	76.63	19.11
	0	53.27	14.11	28.13	11.57
	−5	−6.11	0.78	−6.16	0.70
MHL	Quiet	81.12	16.71	72.65	15.39
	10	61.37	19.16	28.64	15.74
	5	21.63	16.16	13.88	17.32
	0	6.91	12.19	−1.20	5.92
	−5	−6.36	0.80	−6.61	0.55

Abbreviations: RAU, rationalized arcsine unit; SNR, signal-to-noise ratio.

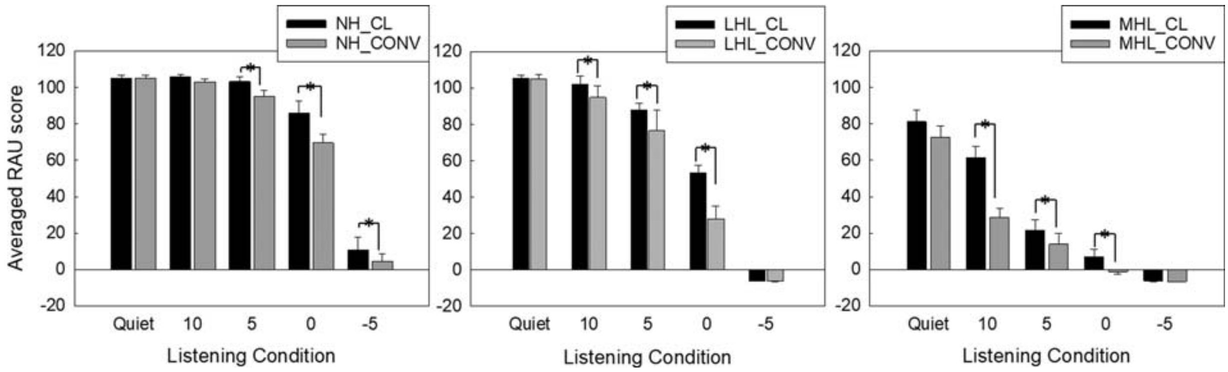

Fig. 2 Averaged intelligibility scores with standard errors for clear speech (CL) and conversational speech (CONV) in the normal hearing (NH) group (left panel), less hearing-loss (LHL) group (middle panel), and more hearing-loss (MHL) group (right panel) as a function of the listening condition (quiet and 4 dB signal-to-noise ratio [SNR] conditions). Asterisks indicate statistical significance.

across all listening conditions was 11.46 RAU. Averaged clear speech benefits increased as hearing sensitivity decreased.

Averaged intelligibility scores with SEs for clear speech and conversational speech under each listening condition and for each group are shown in ►**Fig. 2**. To identify whether averaged RAU scores for clear speech is significantly higher than those for the conversational speech in identical group and noise conditions, estimates of fixed effects were conducted. In the NH group, intelligibility scores achieved in response to clear speech were significantly higher than those obtained in response to conversational speech in listening conditions with 5 dB SNR (103.21 RAU vs. 95.22 RAU, coefficient = 1.401, $p < 0.001$), 0 dB SNR (86.01 RAU vs. 69.51 RAU, coefficient = 3.240, $p < 0.001$), and −5 dB SNR (10.57 RAU vs. 4.52 RAU, coefficient = 0.504, $p = 0.021$). In the LHL group, intelligibility scores achieved in response clear speech were significantly higher than those obtained in response to conversational speech in listening conditions with 10 dB SNR (102.17 RAU vs. 94.81 RAU, coefficient = 0.976, $p = 0.011$), 5 dB SNR (87.69 RAU vs. 76.63 RAU, coefficient = 2.280, $p < 0.001$), and 0 dB SNR (53.27 RAU vs. 28.13 RAU, coefficient = 4.975, $p < 0.001$). In the MHL group, intelligibility scores achieved in response clear speech were significantly higher than those obtained in response to conversational speech in listening conditions with 10 dB SNR (61.37 RAU vs. 28.64 RAU, coefficient = 5.058, $p < 0.001$), 5 dB SNR (21.63 RAU vs. 13.88 RAU, coefficient = 1.220, $p < 0.001$), and 0 dB SNR (6.91 RAU vs. −1.20 RAU, coefficient = 1.691, $p < 0.001$).

Discussion

The overall results for the present study indicate meaningful insight. First, compared with conversational speech, Korean clear speech is beneficial for listeners across various hearing sensitivity conditions from NH to moderately severe hearing loss. Therefore, Korean clear speech is a useful strategy to improve speech intelligibility for Korean listeners with various degrees of hearing loss. Second, the benefits for Korean clear speech were varied depending on listening conditions and groups with different hearing sensitivity. Thus, the results of this study can be used to establish individualized effective listening strategies for Korean listeners. For example, if a listener has moderate-to-severe hearing loss and the listener's hearing aids do not provide enough intelligibility benefits, clear speech training by audiologists (or hearing professionals) is suggested for the listener's spouse or family members who should be informed that the use of clear speech may be beneficial in situations where speech level is equal to, or louder than background noise.

Although intelligibility benefits for Korean clear speech varied depending on the listening conditions for all groups, Korean clear speech benefits seem larger across groups with hearing loss than the groups with NH. In English clear speech studies, however, the degree of intelligibility benefits for clear speech according to hearing sensitivity differed slightly. For example, Ferguson[2] reported that the average intelligibility benefit for English clear speech is 8.8 RAU for older adults with mild-to-moderate hearing loss and this benefit was identical to that among young adults with NH.[18] Additionally, Maniwa et al[3] reported that average clear speech benefits for English fricative recognition were 4.6% for young adults with NH and 3.9% for young adults with simulated sloping type hearing loss. Because each study measured the benefits of clear speech under different conditions, including various listening conditions, speech materials, and degrees of hearing loss exhibited by the enrolled listeners, direct comparison between previous studies of English clear speech benefits and the current study would be ineffective. However, the results of the present study indicate the possibility that the degree of benefit of Korean clear speech for listeners with hearing loss is similar or higher to that for English clear speech. Thus, using Korean clear speech as a suggested communication strategy and thus improving speech intelligibility for Korean listeners with hearing loss may provide similarly significant benefits as the employment of English clear speech.

This study has several limitations that require follow-up studies. First, the present study focused on clear speech benefits across listeners' hearing status. However, Ferguson[2] found that talker variability has a larger effect on the clear speech intelligibility than listener variability. Therefore, talker variability on Korean clear speech may be considered in further research. Second, the present study used a single instruction ("while speaking clearly") for recording clear speech stimuli. However, Lam and Tjaden[24] found that clear speech intelligibility varied depending on the instruction. Therefore, additional research may be required to examine the most effective instruction for the Korean clear speech.

The present study provides information on the actual benefits of Korean clear speech for listeners with varying hearing sensitivities. Compared with conversational speech, intelligibility benefits of Korean clear speech were significant for listeners with NH, mild-to-moderate hearing loss, and hearing-aid-equipped individuals with moderate-to-severe hearing loss. Moreover, the benefits of Korean clear speech were significant when the noise level was equal or less to the signal (speech) level. Therefore, Korean clear speech is a useful communication strategy for both listeners with NH and those with hearing loss in the presence of noise. The data obtained from this study will help improve understanding of the impact of Korean clear speech and how it changes with hearing sensitivity. Furthermore, audiologists and hearing professionals will be able to use our findings to inform communication strategies for native Korean-speaking patients with hearing loss undergoing auditory rehabilitation.

Disclosure
Pilot data of this paper were presented at the American Auditory Society Annual Meeting (2019) as a poster presentation. This paper has not been submitted at any journals.

Ethical Statement
This study was approved by the institutional review board of Hallym University (HIRB-2018–003) and each participant received a written explanation of the study aims, protocol, and procedures and provided written informed consent before participating.

Conflicts of Interest
None declared.

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