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Original Article

Right-Ear Advantage for Unaided and Aided Speech Perception in Noise in Older Adults

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OBJECTIVE: To investigate whether the magnitude of the right-ear advantage (REA) for speech perception in noise decreased in aided conditions as compared with unaided conditions in older adults bilaterally fitted with hearing aids. A secondary aim was to determine the effect of audibility on the right- and left-ear processing for speech stimuli in both aided and unaided conditions.

METHODS: Forty-two older adult, bilateral hearing-aid users were selected. Pure-tone audiometry and the hearing-in-noise test (HINT) were carried out and real-ear insertion gain (REIG) was measured in all participants. All HINT stimuli were delivered via loudspeakers in the free field in both aided and unaided conditions.

RESULTS: Right-ear scores for HINT were significantly better than the left ear in both unaided and aided conditions. No significant differences in the magnitude of the REA between the unaided HINT and aided HINT scores were found. Regression models showed that audibility explained 47% and 53% of the variance in unaided HINT scores in the right and left ears, respectively. For the aided HINT scores, age and audibility explained 46% of the variability for the left-ear scores, while for the right ear, the only remaining significant variable in the model was REIG, which explained 12% of the right-ear HINT scores.

CONCLUSION: Right-ear processing is significantly more efficient for speech stimuli in both unaided and aided conditions in older adults. Audibility affected unaided speech perception in right and left ears similarly however this was not the case in the aided condition. Audibility was associated with aided speech perception in noise in the left ear only.

KEYWORDS: Hearing loss, hearing aids, older adults, speech perception

INTRODUCTION

The existence of a right-ear advantage (REA) for speech stimuli was originally proposed by Kimura in 1960s.[1,2] Kimura suggested that due to the strength of the crossed auditory pathways (i.e., stronger than the ipsilateral pathways), the right ear (RE) has direct access to the language areas located in the left hemisphere. Thus, when speech stimuli are presented in competition with other stimuli such as noise or other verbal stimuli in the contralateral ear, listeners with speech represented in the left hemisphere are more efficient on the RE. Subsequent studies specifically investigating speech perception in noise in adults have confirmed the existence of a REA.[3-7] Therefore, the RE pathway (for persons with speech represented in the left hemisphere) is predominant for the processing of speech-like stimuli.

Some authors have been interested in exploring whether RE and LE processing differences (i.e., REA) increase with aging.[5,8] For example, using the hearing-in-noise test[9] (HINT) Tadros et al.[5] investigated the magnitude of the REA for speech perception in a group of older adults with normal hearing thresholds along with a group of older adults with high-frequency hearing loss.

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Both groups showed a systematic REA for speech perception in noise. The same authors suggested that aging caused a greater decline in the left-ear pathway compared with the RE pathway and that this decline was not necessarily affected by age-related declines in audibility. Several other authors have also suggested that aging mostly affects left-ear processing.[4,10,11] Therefore, it seems that age-related changes in the central auditory nervous system mainly affect the nondominant auditory pathway (left-ear pathway) increasing the REA for speech perception tasks. Note that several authors have claimed that speech perception difficulties in older adults are mainly explained by declines in audibility.[3,11,12-14] Thus, it may be suggested that the degree of hearing loss (i.e., audibility) is also associated with the magnitude of the REA for speech perception in older adults. This is because declines in audibility (i.e., decrease in external redundancy) is likely to affect more severely the nondominant auditory pathway (i.e., left-ear pathway which presents lower internal redundancy than the right auditory pathway). If this hypothesis is true, then the magnitude of the REA for speech stimuli in older adults should decrease when audibility is restored by for example hearing aids. In addition, audibility should stronger account for left-ear processing of speech stimuli than RE processing.

The primary aim of this exploratory study was to investigate whether the magnitude of the REA for speech perception in noise decreased in aided conditions as compared with unaided conditions in older adults bilaterally fitted with hearing aids. A secondary aim was to determine the effect of audibility (i.e., hearing loss) on the RE and LE processing for speech stimuli in both unaided and aided conditions in older adults.

METHODOLOGY

This is a cross-sectional study with Australian older adults who were hearing-aid users. All participants gave written informed consent. The research protocol was approved by the Ethics Committee of the University of Queensland.

Participants

Forty-two older adults aged between 61 and 87 years (mean age = 72.69 ± 6.90) with symmetrical sensorineural hearing loss and bilaterally fitted with hearing aids were selected. All participants were right-handed, native English speakers and reported no history of neurological disorders or other major diseases. They self-reported having a problem with their hearing since between 3 and 40 years ago (mean: 14.14 years). They were hearing aid users between 2 months and 35 years ago (mean: 6.3 years). They acquired the most recent hearing aids (which were used during the experiments in this study) between 1 month and 6 years ago (mean: 1.9 years). The type of hearing aids included in the ear and behind the ear and most of them did not have a remote control. A 7.1% ($n=3$) reported that they did not wear their hearing aids, 9.5% ($n=4$) wore their hearing aids less than 1 h/day, 16.7% ($n=7$) between 1 and 4 h/day, 16.7% ($n=7$) between 4 and 8 h/day, and 50% ($n=21$) wore their hearing aids more than 8 h/day.

Procedures

Participants were selected from a registry of older adults from the University of Queensland who had previously consented to be contacted for research purposes. Initial information about the study was mailed to the prospective participants (i.e., hearing aid users) and those who replied back were contacted via telephone for an interview. Participants who agreed to participate in the study were scheduled for an evaluation session with the aim to determine the presence of symmetrical sensorineural hearing loss and if so, the session continued with the experiments designed for the purposes of this study.

Otoscopies were carried out to exclude pathological alterations of the external ear canal and tympanic membrane. Tympanometry was conducted to exclude middle-ear dysfunction. Pure-tone audiometry was carried out in a soundproof room using the modified Hughson and Westlake[15] procedure as described by Carhart and Jerger.[16] Air-conduction pure-tone thresholds were obtained at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. Bone-conduction thresholds were obtained at 500, 1000, 2000, 3000, and 4000 Hz. An air-conduction pure-tone threshold average (PTA_4) across frequencies (500, 1000, 2000, and 4000 Hz) was obtained for the RE and LE in every single participant. All participants should have presented with symmetrical sensorineural hearing loss. This was defined as an interaural pure-tone average difference (500, 1000, 2000, and 4000 Hz) of no more than 10 dB.[17]

Hearing-in-Noise Test (HINT)

Speech perception in noise was assessed using the HINT.[9] All stimuli were delivered via loudspeakers in the free field. Signal-to-noise ratios (SNRs) for 50% speech discrimination were calculated. For each condition, a set of 20 sentences using American English was presented in noise, spectrally matched to the average long-term spectrum of the speech material of the sentences. Nilsson et al.[9] described that this noise was created based on the average long-term spectrum of the sentences used in the HINT which was obtained by playing back the sentences continuously. The long-term average spectrum over a 12-kHz bandwidth was reached after 72 sentences as no further changes in the long-term spectrum were observed after this point.[9]

Two procedures were used in this study. First, the noise was delivered directly to the RE from a loudspeaker located at 1 m from the person's head at 90 azimuth along with the sentences delivered to the front from a loudspeaker located at 1 m from the person's head at 0 azimuth. This condition is referred as HINT left ear (HINT LE). Second, noise was delivered directly to the LE from a loudspeaker located at 1 m from the person's head at 270 azimuth along with the sentences delivered to the front from a loudspeaker located at 1 m from the person's head at 0 azimuth. This condition is referred as HINT RE. Under this paradigm, it was expected that the ear contralateral to the ear that receives the masking noise processed the speech stimuli. Scores were obtained through an adaptive procedure in which the sentence sound pressure levels were adjusted according to the accuracy of the listener responses. The REA for unaided and aided speech perception in noise was calculated by subtracting the HINT RE scores from the HINT LE scores. In this formula, positive values indicate better RE performance on speech processing, while negative values indicate better left-ear performance. In the aided condition, participants wore both their hearing aids with a program and settings of their preference.

Matching Target Insertion Gain

Initially, the participants' hearing aids were checked to determine they were working properly. Then, using an Aurical FreeFit system (Otometrics, Taastrup, Denmark), real-ear insertion gains (REIG) were measured for both right and left hearing aids in each participant without changing any parameters of their programs and settings; thus, the difference between the REIG and the National Acoustics Labs, Non-Linear, version 1 (NAL-NL1) target REIG for 65 dB SPL input was obtained. The mismatch between the measured REIG and the NAL-NL1 target REIG for 65 dB SPL input was obtained across frequencies. Then, the average of the mismatch between the measured REIG and the NAL-NL1 target REIG for 65 dB SPL input across frequencies (250, 500, 1000, 2000, 3000, 4000, and 6000 Hz) was obtained ($REIG_{mismatch}$) in each ear. The $REIG_{mismatch}$ was recorded and further used for statistical analyses.

Statistical Analyses

Initially, Wilcoxon signed-rank tests were computed to compare RE and LE results for pure-tone audiometry (PTA_4), HINT (unaided and aided), REA for HINT (unaided and aided), and $REIG_{mismatch}$. Then, a Spearman correlation matrix was computed to determine possible correlations between unaided and aided HINT scores for the RE and LE and the factors of age, PTA_4 RE, PTA_4 LE, $REIG_{mismatch}$ RE, and $REIG_{mismatch}$ LE. Finally, bivariate and multivariate regression models were constructed to independently investigate possible associations between the dependent variable (i.e., unaided and aided HINT scores for the RE and LE) and the independent factors of age, PTA_4 RE, PTA_4 LE, $REIG_{mismatch}$ RE, and $REIG_{mismatch}$ LE. For the multivariate models, a backward elimination technique was used to select the remaining significant variables in the adjusted analysis, using a selection criterion of $\alpha < 0.05$. All statistical analyses were performed using SPSS software version 24 (SPSS Inc., Chicago, USA).

RESULTS

As described in Table 1, all participants had a bilateral moderate sensorineural hearing loss and showed no significant differences between both ears for PTA_4 (500-4000 Hz) ($Z=-0.52$, $P=.59$). The mismatch between the measured REIG and the NAL-NL1 target REIG ($REIG_{mismatch}$) was 7 dB on average for both ears (i.e., 7 dB below the NAL-NL1 target REIG for 65 dB SPL input). No significant differences for $REIG_{mismatch}$ between the right and left hearing aids were observed ($Z=-0.017$, $P=.986$). HINT RE (i.e., noise presented to the LE) showed significantly better results (i.e., lower SNR for 50% speech discrimination) than HINT LE (i.e., noise presented to the RE) in both unaided ($Z=-2.583$; $P=.010$) and aided ($Z=-2.726$; $P=.006$) conditions. The REA for both unaided and aided speech perception (i.e., HINT scores) was 1.4 dB SNR. The REA did not significantly differ between the unaided and aided conditions ($Z=1.20$, $P=.23$). Figure 1 displays the HINT scores for the RE and LE along with the REA.

Table 1. Mean, Standard Deviation, Minimum, and Maximum for Pure-Tone Average (PTA_4, 0.5-4 kHz), HINT Unaided, HINT Aided, and $REIG_{mismatch}$ for the Right and Left Ears in the Group of Participants (n=42)

Variable	Mean (SD)	Min	Max	Wilcoxon Signed Rank Test (*P* Value)
Age	72.69 (6.90)	61.00	87.00	
PTA_4 RE	41.86 (12.15)	17.00	63.75	$Z=-0.52$ ($P=.59$)
PTA_4 LE	45.55 (12.98)	10.00	76.25	
HINT-UA RE	1.63 (5.63)	−7.00	16.80	**$Z=-2.58$ ($P=.01$)**
HINT-UA LE	3.05 (6.49)	−7.30	21.30	
HINT-A RE	−0.64 (3.48)	−7.00	10.80	**$Z=-2.72$ ($P=.006$)**
HINT-A LE	0.84 (4.41)	−13.30	9.40	
$REIG_{mismatch}$ RE	−8.13 (7.00)	−33.60	3.80	$Z=-0.01$ ($P=.98$)
$REIG_{mismatch}$ LE	−6.53 (7.90)	−20.30	21.10	

RE, right ear; LE, left ear; UA, unaided; A, aided; HINT, hearing-in-noise test. Scores are in dB SNR; $REIG_{mismatch}$, mismatch between the measured real-ear insertion gain (REIG) and the NAL-NL1 target REIG.

Table 2 displays the correlation rank coefficients (Spearman's Rho) between unaided and aided speech perception in noise (i.e., HINT scores) and the variables of age, PTA_4, and $REIG_{mismatch}$. Unaided HINT RE was significantly correlated with age, PTA_4 RE, and PTA_4 LE. Unaided HINT LE was significantly correlated with age, PTA_4 RE, and PTA_4 LE. Aided HINT RE was significantly correlated with $REIG_{mismatch}$ RE, while aided HINT LE was significantly correlated with age, PTA_4 RE, and PTA_4 LE. Finally, significant correlations among the HINT test scores (e.g., unaided RE with aided RE, unaided RE with unaided LE) were found.

Regression Analyses

Bivariate and multivariate regression models were performed to determine which of the 3 factors (age, PTA_4, and $REIG_{mismatch}$) best-predicted speech perception in noise in both unaided and aided conditions for each ear (see Tables 3 and 4). In the unaided condition, the results of the multivariate regression models indicated that audibility (PTA_4) significantly predicted 49% of the variability in the HINT RE score and 54% of the variability in the HINT LE score. For the aided condition, the results indicated that amongst all 3 factors, age and PTA_4 LE significantly predicted 49% of the HINT LE score, whereas only $REIG_{mismatch}$ RE significantly predicted 12% of the HINT RE score.

DISCUSSION

The aim of this study was to investigate whether the magnitude of the REA for speech perception in noise decreased when audibility was restored with the use of hearing aids in older adults. In addition, in the same population, we aimed to investigate the effect of audibility on RE and LE processing for speech stimuli in noise in both unaided and aided conditions. We found that participants obtained significantly better results for HINT RE (i.e., noise presented to the LE) compared with HINT LE (i.e., noise presented to the RE). This was true for both unaided and aided conditions. The magnitude of the

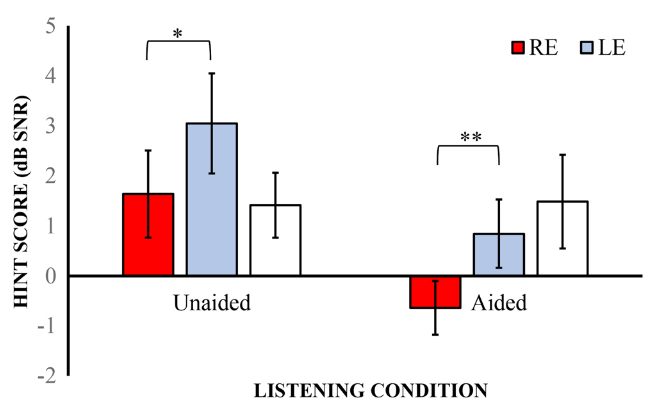

Figure 1. Mean HINT scores for the right and left ears along with the REA. RE, right ear; LE, left ear; REA, right-ear advantage; HINT, hearing-in-noise test. Scores are in dB SNR (signal-to-noise ratio). Significant differences are indicated by an *P < .05 or **P < .01. No significant differences in the REA (white bars) between the unaided and aided conditions were found.

Table 2. Correlation Matrix Between Unaided- and Aided-HINT Scores and Age, Sound Detection (PTA_4), and the Mismatch Between the Measured REIG and the NAL-NL1 Target REIG ($REIG_{mismatch}$)

	HINT-UA		HINT-A		Age	PTA_4 RE	PTA_4 LE	$REIG_{mismatch}$ RE	$REIG_{mismatch}$ LE
	RE	LE	RE	LE					
HINT-UA RE	·								
HINT-UA LE	0.581**	·							
HINT-A RE	0.316*	−0.011	·						
HINT-A LE	0.356*	0.770**	0.131	·					
Age	0.306*	0.430**	0.010	0.484**	·				
PTA_4 RE	0.713**	0.713**	0.165	0.481**	0.428**	·			
PTA_4 LE	0.536**	0.697**	0.155	0.528**	0.247	0.699**	·		
$REIG_{mismatch}$ RE	0.085	0.110	−0.335*	−0.148	0.165	−0.066	0.009	·	
$REIG_{mismatch}$ LE	0.154	0.254	−0.267	−0.074	0.066	0.241	−0.015	0.511**	·

PTA_4, pure-tone average from 0.5 to 4.0 kHz; RE, right ear; LE, left ear; UA, unaided; A, aided; HINT, hearing-in-noise test. Scores are in dB SNR; $REIG_{mismatch}$, mismatch between the measured real-ear insertion gain (REIG) and the NAL-NL1 target REIG. Significant correlations are indicated by an *$P < .05$ or **$P < .01$.

REA for speech perception in noise was approximately 1.4 dB SNR for both unaided and aided conditions. Therefore, the magnitude of the REA for speech perception in noise did not decrease when audibility was restored by the hearing aids. Therefore, we reject the hypothesis that audibility accounts, at least partially, for the increase in REA observed in older adults. We conclude that the presence of an REA for speech perception in noise observed in this group of participants is supported by previous studies suggesting stronger right-ear/left-hemisphere connections leading to better performance when speech stimuli are processed by the RE pathway as opposed to the left-ear pathway.[1,2,4,5,18,19] The REA for unaided speech perception in noise among older adults is consistent with previous studies (e.g., Tadros et al.[5]). To the best of our knowledge, this is the first study investigating differences between RE and LE presentations for aided speech-perception-in-noise performance in older adults. This study suggests that the REA is not modified by improvements in audibility and thus this piece of information should be considered for aural rehabilitation strategies in older adults. For example, clinicians may include this aspect when counseling older adults who present a large REA and who utilize hearing aids. Also, the presence of a large REA may be incorporated when providing communication strategies to older adults with hearing loss. Finally, the REA for speech perception may be considered for hearing aid fitting strategies. Cox et al.[20] reported that adults who presented more equivalent results between ears for dichotic listening were more likely to prefer to use 2 hearing aids. We suggest that further studies should be carried out with the aim to determine whether the results found in the present study can be replicated.

To better understand the increase of the REA in older adults as compared with younger adults, we were particularly interested in determining the effect of audibility and age on RE and LE processing for speech stimuli in both unaided and aided conditions. For this, we conducted correlation analyses along with regression models for unaided and aided HINT scores in the RE and LE. For the unaided condition, we found that audibility was significantly associated with HINT scores in the RE and LE. Audibility alone explained around 50% of the variability in HINT scores in both ears. Therefore, the effect of audibility on speech perception in noise is similar for both ears in the unaided condition. However, when participants executed the speech perception task wearing their hearing aids, audibility was no longer a significant predictor for HINT RE scores. Audibility and age significantly predicted aided HINT LE scores, though to a lesser extent as compared with the unaided condition. Thus, the RE pathway in the aided condition was able to overcome the effect of audibility, but the same was not true for the left-ear pathway. This

Table 3. Bivariate and Multivariate Linear Regression Analyses for Unaided HINT Scores

Characteristic	Bivariate Model			Initial Multivariate Model		Final Multivariate Model	
	Beta	*P*	R^2	Beta	*P*	Beta	*P*
Right ear							
Age	0.257	.100	0.066	−0.091	.481		
PTA RE	0.701	$P < .0001$	**0.492****	0.744	$P < .0001$	0.701	$P < .0001$
				Adjusted $R^2 = 0.499$**		**$R^2 = 0.492$****	
Left ear							
Age	0.383	.012	**0.147***	0.209	.058		
PTA LE	0.736	$P < .0001$	**0.541****	0.682	$P < .0001$	0.736	$P < .0001$
				Adjusted $R^2 = 0.561$**		**$R^2 = 0.541$****	

RE, right ear; LE, left ear; UA, unaided condition; A, aided condition; HINT, hearing-in-noise test. Scores are in dB SNR. Significant associations for each model are indicated by an *$P < .05$ or **$P < .01$.

Table 4. Bivariate and Multivariate Linear Regression Analyses for Aided HINT Scores

Characteristic	Bivariate Model			Initial Multivariate Model		Final Multivariate Model	
	Beta	*P*	R^2	Beta	*P*	Beta	*P*
Right ear							
Age	−0.065	.681	0.004	−0.083	.639		
PTA RE	0.048	.763	0.002	0.203	.253		
$REIG_{mismatch}$ RE	−0.349	.034	**0.122***	−0.309	.070	−0.349	.034
				Adjusted R^2 = 0.156		**R^2 = 0.122***	
Left ear							
Age	0.495	.001	**0.245****	0.350	.023	0.362	.004
PTA LE	0.614	*P* < .0001	**0.377****	0.396	.011	0.521	*P* < .001
$REIG_{mismatch}$ LE	0.007	.967	0.001	0.061	.681		
				Adjusted R^2 = 0.301**		**Adjusted R^2 = 0.499*****	

RE, right ear; LE, left ear; UA, unaided condition; A, aided condition; HINT, hearing-in-noise test. Scores are in dB SNR; $REIG_{mismatch}$, real-ear insertion gain for hearing aids. Mismatch between the measured real-ear insertion gain (REIG) and the NAL-NL1 target REIG. Significant associations are indicated by an **P* < .05 or ***P* < .001 and ****P* < .0001.

cannot be explained by differences in amplification or audibility, as no significant differences in $REIG_{mismatch}$ were observed between the right and left hearing aids. Similarly, no significant differences in hearing thresholds were observed between both ears. In addition, the magnitude of the REA remained the same in the aided condition as compared with the unaided condition. We hypothesize that this may be explained by an overall weaker left-ear pathway for the processing of speech stimuli, as suggested by Kimura.[1,2] Note that the digital noise reduction algorithms used by participants' hearing aids were not investigated in this study and therefore this is considered as a limitation. Hearing aids may have affected participants' performance, especially considering that speech was presented directly in front and noise from the side (90 azimuth/270 azimuth). Noise may have been better reduced from the left side than the right side affecting in this way the results found in this study. We suggest that future research in this field should consider this variable in the study design.

In the presence of symmetrical hearing loss, unaided speech perception is very difficult for listeners no matter what ear processes the speech stimuli, as due to poor audibility the acoustic features of speech cannot be fully accessed. Despite these difficulties, RE processing is more efficient due to the direct access to the left hemisphere. Therefore, an REA for speech perception (in noise) is still observed in the presence of symmetrical hearing loss. In addition, hearing loss implies not only poor sound detection but also decrements in the outer hair cell (OHC) function[21-23] and frequency resolution,[22,25] as well as a reduction in central auditory processing,[4,21,25] among other aspects. All these factors, along with poor audibility, make the processing of speech stimuli difficult in the presence of hearing loss. However, audibility is the key aspect, as sounds that are not perceived cannot be processed spectrally or temporally. When audibility is partially restored with the use of hearing aids, then variables other than audibility which are not improved with the use of hearing aids (e.g., OHC function) should explain the variability in speech perception tasks. This can be especially true for the RE pathway. Considering that the left-ear pathway is weaker than the RE, the former requires more external redundancy (i.e., acoustic features of speech stimuli) than the latter to process speech. Thus, considering that hearing aids do not fully restore audibility, the weaker left-ear pathway still depends on audibility (external redundancy) to accurately process speech stimuli. The strong RE pathway requires less external redundancy to accurately process speech and thus it can compensate the remaining audibility problems (i.e., access to acoustic features of speech) with the use of hearing aids.

Finally, our results also showed that age explained participants' performance on the left-ear processing of speech stimuli but not on the RE processing. This result is in agreement with previous studies showing that aging predominantly affects the left auditory pathway.[3,4,9,14,18,19]

CONCLUSION

The results of this study show that the magnitude of the REA for speech perception in noise does not decrease when audibility is partially restored with hearing aids in older adults. In the unaided condition, audibility affects RE and LE processing for speech stimuli to a similar extent. When audibility is partially restored with hearing aids, older adults' performance on RE processing does not depend on the level of hearing loss, as opposed to the LE. Further research is required to better understand what factors other than audibility and age are associated with ear differences in older adults' performance on speech-perception-in-noise tasks.

Ethics Committee Approval: The research protocol was approved by the Ethics Committee of the University of Queensland.

Informed Consent: Written consent was obtained from all participants.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – A.F.; L.H.; Design - A.F.; L.H.; Supervision - A.F.; L.H.; Resource - A.F; L.H.; R.A.O.; Materials -A.F.; L.H.; Data Collection and/or Processing - A.F; Analysis and/or Interpretation - L.B.; A.F.; A.I.; R.A.O; L.H.; Literature Search - L.B.; A.F.; A.I.; Writing - L.B.; A.F; Critical Reviews - A.F.; L.H.

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Conflict of Interest: The authors have no conflict of interest to declare.

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