The Effect of Background Noise on Immediate Free Recall of Words in Younger and Older Listeners with Hearing Loss

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Abstract

Background Auditory working memory is a crucial factor for complex cognitive tasks such as speech-in-noise understanding because speech communication in noise engages multiple auditory and cognitive capacities to encode, store, and retrieve information. An immediate free recall task of words has been used frequently as a measure of auditory working memory capacity.

Purpose The present study investigated performance on the immediate free recall of words in quiet and noisy conditions for hearing-impaired listeners.

Research Design Fifty hearing-impaired listeners (30 younger and 20 older) participated in this study. Lists of 10 phonetically and lexically balanced words were presented with a fixed presentation rate in quiet and noise conditions. Target words were presented at an individually determined most comfortable level (MCL). Participants were required to recall as many of the words in an arbitrary order immediately after the end of the list. Serial position curves were determined from the accuracy of free recall as a function of the word position in the sequence.

Data Collection and Analysis Three-way analyses of variance with repeated measures were conducted on the percent-correct word recall scores, with two independent within-group factors (serial position and listening condition) and a between-group factor (younger, older).

Results A traditional serial position curve was found in hearing-impaired listeners, yet the serial position effects depended on the listening condition. In quiet, the listeners with hearing loss were likely to recall more words from the initial and final positions compared with the middle-position words. In multi-talker babble noise, more difficulties were observed when recalling the words in the initial position compared with the words in the final position.

Conclusion Without a noise, a traditional *U*-shaped serial position curve consisting of primacy and recency effects was observed from hearing-impaired listeners, in accord with previous findings from normal-hearing listeners. The adverse impact of background noise was more pronounced in the primacy effect than in the recency effect.

Keywords
- serial position effect
- primacy effect
- recency effect
- working memory
- hearing loss

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Working memory is a cognitive system with a limited capacity that is responsible for temporarily storing and manipulating information during ongoing processing.[1] Audiologists have become increasingly interested in measuring auditory working memory since working memory capacity is associated with a person's successful speech understanding in adverse environments such as noisy conditions.[2–6]

The immediate free or serial recall of words has been one of the common tasks to measure an individual's auditory working memory capacity.[7–11] In both tasks, participants are presented with a list of words, one at a time, and are asked to recall as many of the words immediately after the end of the list. In the free recall task, participants are free to recall the words in an arbitrary order, whereas in the serial recall task, participants are required to recall the words in the same order they were presented. A *U*-shaped serial-position curve is a well-established recall performance because the participants tend to recall more words from the initial (*primacy effects*) and final positions (*recency effects*) than the middle-position words.[9] Traditionally, a serial-position curve has been explained by a dual-component model that assumed separate short-term and long-term memory mechanisms.[9,12,13] The primacy effects (better recall of initial-position words) have been interpreted to reflect the long-term memory capacity because it involves the ability to encode and rehearse the words and then transfer them from short-term storage into the long-term memory.[12] The recency effects (better recall of final-position words) have been thought to involve the short-term memory capacity because it requires the temporary storage in the short-term memory rather than in the long-term memory.[12,13]

When a listener recalls a sequence of words presented in background noise, recall performance can be disrupted by noise. Rabbitt[14,15] reported that the noise impaired recall performance of young adults, even when the noise did not produce recognition errors. Kjellberg et al[16] found a negative effect of broadband noise on word recall performance. Other previous studies compared the recall performance in quiet and in multi-talker babble noise and found that the multi-talker noise hindered recall performance.[17,18] Taken together, it appears that background noise occupies working memory capacity and impedes the recall performance. However, the majority of findings on the adverse effect of noise were obtained from normally hearing listeners.

Hearing loss may require more allocation of cognitive resources and extra efforts, leaving fewer available working memory resources for speech recognition and recall tasks.[19] A measure of the ability to recall spoken words can be informative when understanding speech comprehension of hearing-impaired listeners.. Rudner et al[20] measured working memory capacity of hearing-impaired listeners with visually presented sentences (reading span task) and concluded that working memory was crucial for speech-in-noise understanding of hearing-impaired listeners, regardless of aided or unaided condition. Souza and Arehart[21] also demonstrated that greater speech-in-noise understanding difficulties were observed from listeners with poorer working memory capacity, even after accounting for age and hearing loss. Ng et al[22] conducted a Sentence-final Word Identification and Recall test to hearing aid users and reported a negative effect of noise on word recall. Smith et al[5] developed the Word Auditory Recognition and Recall Measure and found that the recall performance of hearing-impaired listeners provided additional information beyond the routine hearing tests. These findings suggested a need for the working memory measure when assessing the communication challenges of hearing-impaired listeners.

The present study aimed to explore the effect of background noise on the serial position effect in listeners with hearing loss. We hypothesized that the immediate free recall of words might be disrupted by noise, but the adverse effect of background noise might be different across the serial positions. The research questions of this study are as follows. (1) Would a traditional serial position curve be observed from the immediate free recall task of hearing-impaired listeners? (2) Would the background noise affect the primacy and recency effects differently? (3) Would the free recall of the initial-position words be dissociated with the free recall of the final-position words, supporting the dual nature of the primacy and recency effects?

Methods

Participants

A total of 50 listeners (27 males, 23 females) with symmetrical sloping sensorineural hearing loss participated in this study. Fifty participants were separated into either a younger group (*N* = 30, mean age = 46.4 years, range = 30–59 years) or an older group (*N* = 20, mean age = 70.3 years, range = 65–80 years). All participants were native speakers of Korean and nonhearing aid users. For the experimental testing, each individual's preferred ear was used as a test ear. ►**Fig. 1** displays the mean hearing thresholds of the test ear from 250 to 8,000 Hz for younger and older hearing-impaired listeners. Except for 8,000 Hz, the difference between mean hearing thresholds of younger and older hearing-impaired groups was less than 10 dB from 250 to 4,000 Hz.

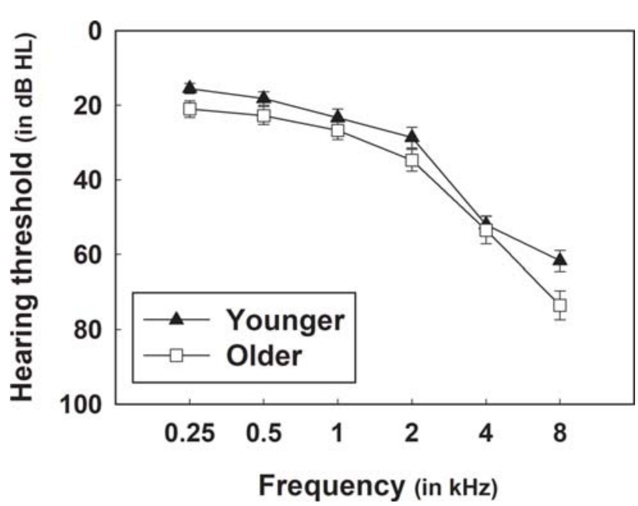

Fig. 1 Mean hearing thresholds of younger and older hearing-impaired listeners as a function of the octave-scale frequencies (error bar: standard errors).

For the younger group, the mean pure tone threshold average (PTA) across 500, 1,000, and 2,000 Hz was 23.50 dB HL (standard deviation [SD] = 10.63) and the mean high-frequency pure tone threshold average (HFPTA) across 1,000, 2,000, and 4,000 Hz was 34.61 dB HL (SD = 9.64). The younger group's mean speech recognition threshold (SRT) was 25.00 dB HL (SD = 9.85), which was in accordance with PTA (paired *t*-test: $t(29) = -1.84$, $p > 0.05$). For the older group, the mean PTA across 500, 1,000, and 2,000 Hz was 27.58 dB HL (SD = 9.28) and the mean HFPTA across 1,000, 2,000, and 4,000 Hz was 38.08 dB HL (SD = 9.84). The older group's SRT was 29.50 dB HL (SD = 9.51), which was not statistically different from their PTA (paired *t*-test: $t(19) = -1.70$, $p > 0.05$). As routine speech audiometry,[23] the mean word recognition score (WRS) in quiet and the sentence recognition score (SRS) in noise were evaluated. The mean WRS in quiet was 85.72% (SD = 9.31) and 84.40% (SD = 9.08) for younger and older groups, respectively. The mean SRS in noise obtained from 0 dB signal-to-noise ratio (SNR) was 67.53% (SD = 10.24) and 60.90% (SD = 12.41) for younger and older group, respectively. The independent *t*-tests revealed no significant difference in the hearing thresholds at octave-scale frequencies from 500 to 4,000 Hz, the PTA, the HFPTA, the SRT, the WRS, and the SRS between younger and older groups ($p > 0.05$).

None of the participants had a history of neurological, language problems, or signs of probable cognitive impairment (score of for the Korean version of the Mini-Mental State Examination ≥ 24).[24] After the routine audiometric battery (pure tone audiometry and speech audiometry), digit forward and backward spans were obtained from all participants as a baseline measurement of working memory capacity. For the digit forward and backward span tests, participants were told to recall the sequence of digits in the order presented (forward) in reverse order from the original presentation (backward). Applying the procedure,[25] the number of digits was increased by one item after every two trials. The mean digit forward span was 6.43 (SD = 0.73) and 5.85 (SD = 1.23) and the mean digit backward span was 2.83 (SD = 1.26) and 2.45 (SD = 0.83) for younger and older group, respectively, showing no significant group differences in both digit forward and backward spans ($p > 0.05$). All the participants provided informed consent before participation (►**Fig. 1**).

Stimuli and Procedure

The performance of free recall of words was evaluated using the 10 sets of 10-word lists. As target words, the present study used prerecorded phonetically balanced monosyllabic words spoken by a single native-Korean female speaker from the Korean Standard Monosyllabic Word Lists for Adults.[26] The monosyllabic words were selected, given that the shorter words are generally easier to recall.[7,27] To avoid any lexical influence on the results,[25] each 10-word list was lexically balanced in terms of word frequency and neighborhood structure (i.e., target word frequency, neighborhood density, and neighborhood frequency). Half of the words were obtained from the lexically easy word lists, and half were from the lexically hard word lists.[28] The average root-mean-square level of each word was equated using Adobe Audition (version 3.0; Adobe Systems Inc., San Jose, CA).

As background noise, eight-talker (four males, four females) babble noise[29] was used because it contains fewer temporal gaps and fluctuations compared with single-talker speech. The amplitude level of an eight-talker babble was matched to the levels of words and then adjusted by Adobe Audition to generate in quiet and 10 dB SNR condition because this SNR is one of the daily listening situations that hearing-impaired listeners often encounter.[30,31]

Each listener was seated in a sound booth, and all the stimuli were monaurally delivered to the test ear through a diagnostic audiometer (GSI 61, Grason-Stadler, Eden Prairie, MN) and supra-aural headphone (Telephonics TDH-39P). Each word was presented at an individually determined MCL. The mean MCL was 60.57 dB HL (SD = 7.45) and 62.10 dB HL (SD = 4.83) for younger and older groups, respectively.

For an immediate free-recall task, the interword interval was 2 seconds and participants were asked to recall the words on the list in an arbitrary order both in quiet and noise conditions. The order between quiet and noise conditions was counterbalanced across participants. The practice run was given to each listener using the words that were not used during experimental testing. No trial-by-trial feedback was provided during the test. The free recall performance was scored as the percentage of correctly recalled words. To determine the serial position effect, 10 words in each list were split up into three positions (initial, middle, and final serial positions). The words from the first three serial positions (first, second, and third positions) in each list were determined to be the initial-position words, the words from the middle four serial positions (fourth, fifth, sixth, and seventh positions) were the middle-position words, and the words from the last three serial positions (eighth, nineth, and tenth positions) were considered the final-position words.

Data Analysis

Data analysis was performed using SPSS 18.0 (SPSS Inc., Chicago, IL), and a significance level of $p < 0.05$ was employed in this study. Three-way analyses of variance with repeated measures were conducted on the percent-correct word recall scores as a dependent variable, with two within-group variables (Serial position: initial, middle, final position; Listening condition: quiet, noise) and one between-group variable (Group: younger, older). When the sphericity assumption was violated, the Greenhouse-Geisser adjustments were applied. If needed, the post hoc multiple comparisons were executed with Bonferroni-corrected *p*-value. The Pearson product–moment correlation analyses were also conducted to evaluate the relations among free recall performances of each serial position.

Results

Effect of Noise on the Free Recall As a Function of Word Position

The present study examined the free recall of words when the word lists were presented in quiet and in multi-talker noise. ►**Fig. 2** shows the percentage of words correctly recalled at each of word positions (first through tenth word position) in

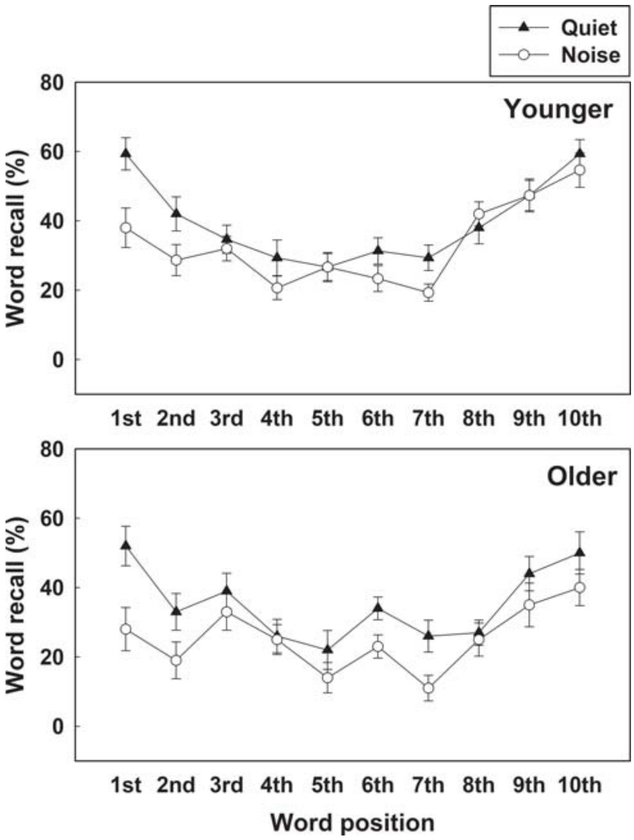

Fig. 2 Mean word-recall scores (%) as a function of the word position in quiet and noise conditions for younger and older hearing-impaired listeners (error bar: standard errors).

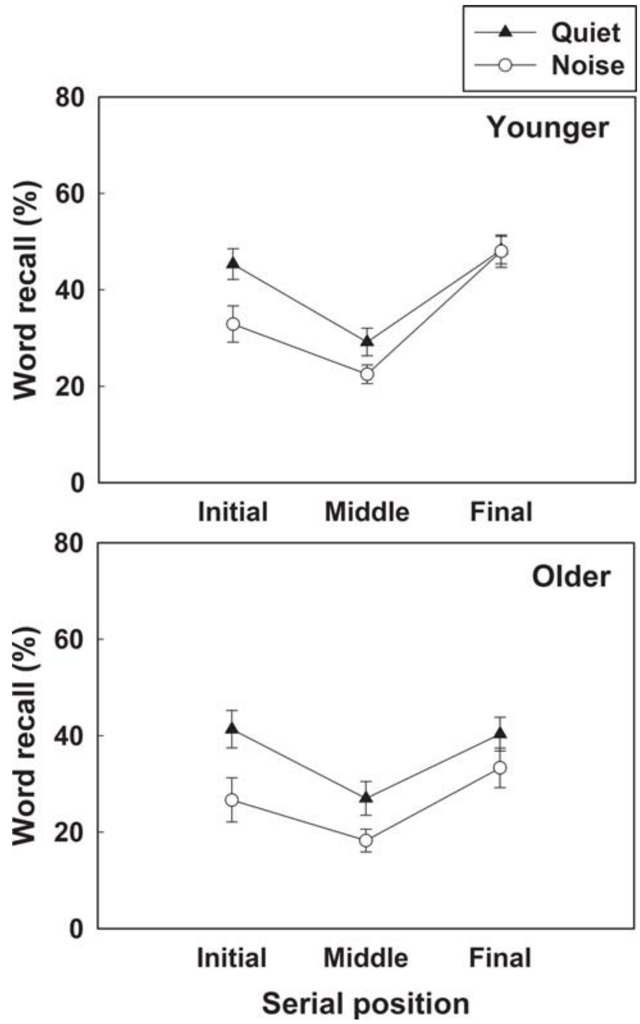

Fig. 3 Mean word-recall scores (%) as a function of serial position (initial, middle, final position) in quiet and noise conditions for younger and older hearing-impaired listeners (error bar: standard errors).

quiet or in noise conditions. In quiet, the mean word recall score of the younger group was 59.33, 42, 34.67, 29.33, 26.67, 31.33, 29.33, 38, 47.33, and 59.33% from first to 10th word position, respectively (standard error, SE = 4.54, 4.92, 4.06, 5.14, 4.22, 3.80, 3.68, 4.63, 4.34, and 4.12). In noise, the younger group's mean word recall score was 38, 28.67, 32, 20.67, 26.67, 23.33, 19.31, 42, 47.33, and 54.67% from first to 10th word position, respectively (SE = 5.70, 4.47, 3.54, 3.39, 3.88, 3.72, 2.48, 3.50, 4.74, and 4.98). For the older listeners, the mean word-in-quiet recall score was 52, 33, 39, 26, 22, 34, 26, 27, 44, and 50% from first to 10th word position, respectively (SE = 5.69, 5.29, 5.12, 4.83, 5.60, 3.28, 4.61, 3.63, 4.94, and 6.07). In noise, the older group's mean word recall performance was 28, 19, 33, 25, 14, 23, 11, 25, 35, and 40% from first to 10th word position, respectively (SE = 6.22, 5.32, 5.29, 4.32, 4.38, 3.33, 3.69, 4.78, 6.30, and 5.23) (►**Fig. 2**).

Effect of Noise on the Free Recall Across Serial Positions

As described earlier, the immediate word recall scores were collapsed from first to third, from fourth to seventh, and from eighth to 10th word positions to be the scores of the initial, middle, and final positions, respectively. ►**Fig. 3** displays the percentage of words correctly recalled at each of the three serial positions (initial, middle, and final position) when measured in quiet or in noise conditions. For the younger listeners, the mean word-in-quiet recall score was 45.33, 29.17, and 48.22% in the initial, middle, and final positions, respectively (SE = 3.17, 2.87, and 2.85). The mean word-in-noise recall score was 32.89, 22.49, and 48% in the initial, middle, and final positions, respectively (SE = 3.74, 1.92, and 3.35). For the older listeners, the mean word-in-quiet recall score was 41.33, 27, 40.33% in the initial, middle, and final positions, respectively (SE = 3.89, 3.51, and 3.49). The mean word-in-noise recall score of the older group was 26.67, 18.25, and 33.33% in the initial, middle, and final positions, respectively (SE = 4.58, 2.35, and 4.10) (►**Fig. 3**).

Three-way analyses of variance with repeated measures were used to explore the effects of group (younger, older), listening condition (quiet, noise), and serial position (initial, middle, and final) on the free recall of words. Main effects of group and listening condition were significant, indicating that the younger group better recalled the words compared with the older group ($F[1, 48] = 7.90$, $p < 0.05$), and the words were better recalled in quiet than in noise ($F[1, 48] = 49.20$, $p < 0.05$). The word recall performance significantly depended on the serial position ($F[1.51, 72.65] = 19.34$, $p < 0.05$). The Bonferroni-corrected multiple paired-comparisons showed that the free recall of middle-position words (24.23%) was significantly lower than free recall of initial-position words (36.56%) and final-position words (42.47%).

The interaction between the listening condition and the serial position was only significant ($F[2, 96] = 3.89$, $p < 0.05$). It indicates that the effect of serial position differed between quiet and noise conditions. Other two-way or three-way interactions were not significant, revealing no different patterns between groups. To further explore the significant interaction, the effect of serial position on collapsed group data was analyzed separately in each condition based on the adjusted *p*-value. The results of post hoc analyses revealed significant serial position effects in each condition (quiet: $F[2, 98] = 16.25$, $p < 0.001$, noise: $F[1.39, 68.10] = 18.15$, $p < 0.001$), but a different pattern on the serial position effects by listening condition. In quiet, the recall scores were similar between the initial (43.73%) and final positions (45.07%), while the recall performance from the middle-position words (28.30%) was significantly lower than performance at other positions. In contrast, with the multi-talker babble noise, the lowest recall score was observed from the middle-position words (20.80%), which was significantly lower than the scores at other positions. In noise, the recall score of the initial-position words (30.40%) was significantly lower than the recall score of the final-position words (42.13%).

In summary, the serial position effect depended on the listening condition. In quiet, the significant primary and recency effects were observed from the traditional serial position curves. However, in noise, the primacy effect was more reduced while the recency effect persisted, suggesting that the adverse effect of noise was more pronounced in the primacy effect.

Correlations among Immediate Free Recall Performances

We conducted Pearson product–moment correlation analyses to examine the relations among the word recall performances (collapsed group data) at initial, middle, and final positions measured in quiet and noisy conditions. As shown in ►**Table 1**, the recall-in-quiet of the initial-position words was significantly associated with the recall-in-noise scores of the initial-position words ($r = 0.63$), but not related to scores of the final-position words regardless of condition. Similarly, the recall-in-quiet of the final-position words was significantly related only to the recall-in-noise score of the final-position words ($r = 0.50$). The dissociations between initial-position and final-position words in any condition seem to support the dual nature of the primacy and recency effects.

The results of additional Pearson correlation analyses showed that the PTA was not related to any performance of word recall possibly due to use of each individual's MCL as a presentation level. The WRS in quiet was not associated with word recall performance from any serial position, indicating that a simple repetition of a single word might not predict the free recall of a sequence of words. The SRS in noise was weakly but significantly related to the recall performances of the initial-position words, but not related to other positions ($r = 0.29$, $p < 0.05$) (►**Table 1**).

Discussion

Working memory capacity is essential for understanding speech comprehension of hearing-impaired listeners.[2,20,21,32] As a measure of working memory capacity, the present study conducted the immediate free recall task of words to listeners with hearing loss since the immediate free recall task requires a person's encoding, maintenance, and retrieval of presented items.

This study aimed to examine the effect of background noise on the serial position effect to understand how a sequence of words can be retained and manipulated simultaneously in memory of hearing-impaired listeners. The present study presented a series of 10-word lists to hearing-impaired listeners at inidivdual's most comfortable level, which provided suprathreshold testing. Overall, older participants recalled significantly fewer words than younger participants, yet the serial position effect was similar to both groups. Without noise, the traditional *U*-shaped serial position curve was observed from both younger and older

Table 1 Correlation coefficients *r* values among the word recall performances at the initial, middle, and final positions obtained from the quiet and noisy conditions

	Recall-in-quiet at initial words	Recall-in-quiet at middle words	Recall-in-quiet at final words	Recall-in-noise at initial words	Recall-in-noise at middle words	Recall-in-noise at final words
Recall-in-quiet at initial words		$r = 0.33^a$	$r = -0.21$	$r = 0.63^b$	$r = 0.45^b$	$r = -0.16$
Recall-in-quiet at middle words			$r = -0.15$	$r = 0.30^a$	$r = 0.42^b$	$r = -0.08$
Recall-in-quiet at final words				$r = -0.09$	$r = -0.04$	$r = 0.50^b$
Recall-in-noise at initial words					$r = 0.23$	$r = -0.30$
Recall-in-noise at middle words						$r = 0.14$
Recall-in-noise at final words						

$^a p < 0.05$.
$^b p < 0.01$.

hearing-impaired listeners. That is, the hearing-impaired listeners tended to recall the first few words (primacy effect) or last few words (recency effect) in a list better than the words in the middle.

Significant primacy and recency effects might support a traditional dual nature of primacy and recency effects.[1,9,12,13,33] Traditionally, the primacy effects have been interpreted to reflect the long-term memory capacity because there may be less competition at the initial stage for the limited working memory capacity. As such, the initial-position words have more opportunities to be rehearsed and transferred to long-term memory. For middle-position words, attention is already divided into the initial-position and middle-position words such that it is less likely to be transferred to long-term memory. Glanzer and Cunitz[13] found that, at a slower rate, there were more substantial primacy effects due to more rehearsal time, whereas there were no differences in recency effects between the slower and faster rates. Unlike the primacy effect, the recency effects have been thought to involve the short-term memory capacity because the final-position words are not rehearsed as much. Instead, the final-position words are likely to be still held in short-term memory and susceptible to rapid decay and phonological interference.[34] The present study showed that the recall performance of the first-position words (primacy effect) was not associated with the recall performance of the final-position words (recency effect). The recall of the final-position words in quiet was only related to the recall of the final-position words in noise with no relations with other position words, which would indicate the dual nature of the primacy and recency effects. The dual-component model explains that the primacy effects (i.e., recall performance of words at the initial position) involve the long-term storage in free-recall performance. In contrast, the recency effects (i.e., recall performance of words at the final position) involve the short-term storage in free-recall performance. Talmi et al[33] used neuroimaging tools to examine the behavioral serial position effects from earlier studies. The authors found that brain areas associated with long-term memory (regions within the hippocampal memory system) were activated with the primacy effects, but not with the recency effects, supporting the dual-store models of the serial position curve.

As expected, in noise, listeners with hearing loss recalled significantly fewer words compared with the quiet condition. Similarly, older adults with mild hearing loss recalled fewer words compared with older adults without hearing loss.[35] van Boxtel et al[36] found that a mild to moderate hearing loss was a significant predictor for explaining verbal memory performance. Interestingly, the adverse effect of noise differed across serial positions for both groups. With the multi-talker noise, the initial-position words in the list were more poorly recalled (reduced primacy effect) relative to the final-position words (persisted recency effect). The more negative effect of noise on primacy effect can be explained by an *effortfulness hypothesis*[15] that suggests, when identifying degraded speech, the perceptual effort might draw resources available for effective storage and rehearsal in memory. Based on this hypothesis, the multi-talker background noise might cause the hearing-impaired listeners to expend more working memory efforts, leaving fewer resources for encoding as well as storage. McCoy et al[19] presented 16 word lists at 75 dB HL and required to recall the last three words in each list to older listeners with good hearing (PTA $<$ 25 dB HL) and with hearing loss (PTA $>$ 25 dB HL). The results showed that older listeners with hearing loss expended more perceptual efforts than good-hearing listeners, supporting an *effortfulness hypothesis*.

In the current study, only the multi-talker noise was presented at a fixed SNR as background noise. Marrone et al[37] revealed that steady-state noise disrupted working memory performance only with high linguistic demand. Rudner et al[38] reported that working memory capacities of hearing-impaired listeners were affected by noise type. Mama et al[39] found that an 8-talker babble noise affected word recall performance to a much more extent than steady-state noise. Heinrich and Schneider[40] found that a high presentation level of distorted words adversely affected memory even after intelligibility was equated for, with a greater effect in older listeners. Taken together, the noise type and the presentation level should be carefully selected for a measure of working memory capacity, and these factors should be explored further.

In conclusion, without noise, a traditional *U*-shaped serial position curve consisting of primacy and recency effects was observed from younger and older hearing-impaired listeners, similar to the previous findings of normal-hearing listeners. The multi-talker babble noise led to more disruption to the primacy effect (presumably involved with long-term storage) compared with the recency effect (probably involved with short-term storage). The recall performance of the primacy-portion words was dissociated with the recall performance of the recency-portion words, supporting the dual nature of the primacy and recency effects.

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Conflict of Interest
None declared.

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