# Clear speech improves listeners' recall[a)]

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The present study examined the effect of intelligibility-enhancing clear speech on listeners' recall. Native ($n = 57$) and non-native ($n = 31$) English listeners heard meaningful sentences produced in clear and conversational speech, and then completed a cued-recall task. Results showed that listeners recalled more words from clearly produced sentences. Sentence-level analysis revealed that listening to clear speech increased the odds of recalling whole sentences and decreased the odds of erroneous and omitted responses. This study showed that the clear speech benefit extends beyond word- and sentence-level recognition memory to include deeper linguistic encoding at the level of syntactic and semantic information. 
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## I. INTRODUCTION

Successful verbal communication involves mapping of variable acoustic input onto stored phonological and lexical representations and maintaining those representations in memory in order to extract sentence-level meaning. Processing degraded, masked, or phonetically ambiguous acoustic signals requires additional cognitive resources leaving fewer resources available for encoding speech in memory (Rönnberg *et al.*, 2013). The present study examined whether acoustic-phonetic enhancements in the form of listener-oriented hyper-articulated clear speech facilitate recall of spoken information for native listeners and listeners who face additional difficulties associated with speech processing in second language (L2).

Adverse listening contexts (e.g., degraded signal quality, background noise, perceiving speech in L2) can raise speech processing demands, leaving fewer available cognitive resources for comprehension and recall of the message [cf. "effortfulness hypothesis," McCoy *et al.* (2005) and Rabbitt (1968, 1990), and cf. "ease of language understanding" model, Rönnberg *et al.* (2013)]. Foreign-accented speech, for instance, was shown to increase cognitive demands during speech perception (Van Engen and Peelle, 2014) and to be recalled less accurately compared to native-accented speech (Chan *et al.*, 2019). In this study, we examined the effect of intelligibility-varying speaking styles on subsequent recall. Unlike clearly spoken speech, conversational speech produced by native speakers can be challenging to process due to pervasive reductions and deletions of speech segments or whole syllables such that it deviates from expected phonological and lexical representations (Johnson, 2004; Mattys *et al.*, 2012; Warner *et al.*, 2009; Warner and Tucker, 2011).

The effect of listener-oriented clear speech on word recognition in noise is well documented [cf. reviews by Smiljanic and Bradlow (2009) and Uchanski (2005)] but less attention has been given to how speech clarity affects memory for spoken language. Van Engen *et al.* (2012) showed enhanced sentence recognition memory for meaningful and clear sentences compared to anomalous and conversational sentences. Gilbert *et al.* (2014) extended these results to sentences presented in noise and to noise-adapted-speech, another intelligibility-enhancing speaking style. More recently, Keerstock and Smiljanic (2018) showed that the clear speech benefit on sentence recognition memory extended to non-native English listeners, and was evident when tested within (audio-audio) and across (audio-text) modalities, suggesting that acoustic-phonetic enhancements promote deeper linguistic encoding at a level abstracted from the input speech.

The current study tested the hypothesis that, by providing optimal and unambiguous speech signals [hyper-speech within the H&H theory of Lindblom (1990)], clear speech may reduce cognitive effort during speech perception and thus improve memory for spoken language compared to conversational speech. We tested this hypothesis by examining memory for spoken language using a cued-recall task. To date, the effect of clear speech on memory has only been assessed via recognition memory, a familiarity decision task ("is this item familiar?") with a binary response (yes/no). In contrast, recall is a more complex task that requires that listeners process the incoming speech signals beyond the surface acoustic level at multiple levels of linguistic structure (phonological, lexical-semantic, morphosyntactic, and syntactic) in order to successfully search and retrieve lexical items and entire units of connected meaning from memory (Gillund and Shiffrin, 1984; Ratcliff, 1978). Limited cognitive resources (e.g., as the result of aging, depressive symptoms, or perceiving speech in noise) impair recall more than recognition (Brand *et al.*, 1992; Ng *et al.*, 2013; Rhodes *et al.*, 2019). To the extent that processing conversational speech demands more cognitive resources, we predicted that its recall might be further impaired in a recall task relative to clear speech.

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Speech perception is additionally affected by fluency in the target language (Best and Tyler, 2007; Cutler *et al.*, 2008; Flege, 1995; Iverson *et al.*, 2003; Kondaurova and Francis, 2008). Non-native listeners recall fewer words in noise than native listeners, although the use of noise-cancelling headphones was shown to improve non-native listeners' performance (Hygge *et al.*, 2015; Molesworth *et al.*, 2014). The difficulty in remembering L2 speech may also arise from the increased recruitment of cognitive resources during speech perception at the expense of storing the information in memory (Best and Tyler, 2007; Flege, 1995; Iverson *et al.*, 2003). Keerstock and Smiljanic (2018) showed that clear speech enhanced recognition memory for non-native listeners suggesting that some of the processing difficulty due to the lack of extensive familiarity with the target language was alleviated, and that sufficient cognitive resources remained available for memory encoding. Here, we extend that line of inquiry by examining whether the acoustic-phonetic clear speech modifications enhance native and non-native listeners' sentence recall. Similar to the improved sentence recognition memory, we expect that clear speech will enhance recall for non-native listeners. However, as some of the clear speech strategies are native-listener oriented (Smiljanic and Bradlow, 2009), the benefit for nonnative listeners may be smaller compared to the native listeners. The results will provide new insights into the link between the signal-related acoustic-phonetic enhancements and relatively signal-independent cognitive processes. Examining the retention of spoken information by L2 speakers also has practical implications as the number of L2 English students in U.S. public schools reached 9.5%, or $4.8 \times 10^6$ students, in 2015 (McFarland *et al.*, 2018). Understanding whether the same memory enhancement strategies apply to both L1 and L2 individuals can inform the use of these strategies in the classroom.

## II. METHODS

### A. Participants

Eighty-eight listeners participated in the study. They were recruited from the University of Texas community and received monetary compensation or class credit for their participation. The non-native English listener group consisted of 31 subjects (22 female; $M_{age} = 22.7$, $SD_{age} = 3.8$). They acquired English on average after age 7.6 (range 5–19) and received no exposure to English at home from parents/caregivers. Information about the non-native listeners' language background is provided in Table I. The native English listeners group (n = 57) included 33 monolingual English listeners (18 female; $M_{age} = 19.6$, $SD_{age} = 1.4$) who reported no exposure to another language before age 6, and 24 native non-monolingual English listeners (15 female; $M_{age} = 18.8$, $SD_{age} = 1.2$) who were exposed to another language from birth alongside with English but reported being English dominant at the time of testing. The early exposure to another language in addition to English, however, did not have significant effect on recall (see the results). All participants signed a written informed consent and filled out a detailed language background questionnaire adapted from the LEAP-Q (Marian *et al.*, 2007). All passed a hearing screening, administered bilaterally at 25 dB hearing level at 500, 1000, 2000, and 4000 Hz.

### B. Stimuli

The stimuli consisted of 72 semantically meaningful sentences from the same sentence pool as in Keerstock and Smiljanic (2018). The sentences contained high-frequency words familiar to non-native listeners [see Calandruccio and Smiljanić (2012) for details about the development of the materials]. All sentences followed the same syntactic structure: they started with a determiner and a noun (e.g., the grandfather), followed by a verb, a determiner, an adjective, and a noun (e.g., drank the dark coffee). The cue written on the page was always the first noun phrase (in italics) and the three keywords to be recalled were always the last three content words (a verb, an adjective, and a noun) (underlined), e.g., "*The grandfather* drank the dark coffee" or "*The mother* baked the delicious cookies." The sentences were produced by a 26-year-old female speaker of American English in conversational and clear speaking style. For the conversational speaking style, the speaker was instructed to read sentences in a casual style, as if talking to someone who is familiar with her speech patterns. For the clear speaking style, she was instructed to read the sentences as if talking to someone who is having difficulty understanding her, such as a non-

TABLE I. Language background information for non-native listeners ($n = 31$).

| | Mean | SD | Range |
|---|---|---|---|
| Age of first exposure to English (in years) | 7.6 | 2.9 | 5–19 |
| Age of arrival to USA (in years) | 16.1 (after 15 yo: $n = 20$) | 9.1 | 0–37 |
| Time spent in USA (in years) | 6.6 | 7.1 | 0–25 |
| Daily exposure[a] to English | 4.8 | 0.5 | 3–5 |
| Daily exposure to L1 | 4.5 | 0.7 | 3–5 |
| Self-estimated proficiency[b] in English | 4.3 | 0.6 | 3.25–5 |
| Self-estimated proficiency in L1 | 4.5 | 0.6 | 2.75–5 |
| L1 | Mandarin ($n = 8$), Spanish ($n = 7$), Hindi ($n = 3$), Korean ($n = 3$), Vietnamese ($n = 2$), Cantonese, French, Gujarati, Indonesian, Malayalam, Marathi, Nepali, Serbian ($n = 1$). | | |

[a]For each language, self-estimated amount of daily exposure on a scale from 1 (no current exposure) to 5 (constant exposure).

[b]For each language, average of self-estimated proficiency for each skill, i.e., writing, speaking, reading, and listening on a scale from 1 (low) to 5 (high).

native listener or a listener with hearing impairment [see Van Engen *et al.* (2012) for elicitation and recording details]. The acoustic analyses showed significantly longer durations, higher mean F0s, larger F0 ranges, and greater energy in the 1–3 kHz range for clear compared to conversational speech [reported in Van Engen *et al.* (2012)]. For sentences used in the current study, we have previously found that word recognition in noise was higher for sentences produced in clear speech compared to conversational speech among native listeners [reported in Van Engen *et al.* (2012)] and non-native listeners [reported in Keerstock and Smiljanic (2018)]. For the current study, the sentences were equalized for RMS amplitude and presented to listeners in quiet (i.e., without added noise).

### C. Procedure

Participants were seated in a sound-attenuated booth facing a computer monitor. Instructions and stimuli were presented with E-Prime 2.0 Psychology Software. The experimental session started with two practice sentences not used in the main experiment. Participants were asked to listen to the sentences and to try and memorize them. After hearing the sentences, they were instructed to write down what they remembered and to guess when uncertain. No feedback was provided. After the practice, listeners heard the 72 test sentences divided into six blocks of 12 sentences. The speaking style presentation was counterbalanced across listeners such that half of the participants heard all the sentences in Block 1, 3, and 5 produced in conversational speech and all the sentences in Block 2, 4, and 6 produced in clear speech, and half of the participants heard all the sentences in Block 1, 3, and 5 produced in clear speech and all the sentences in Block 2, 4, and 6 produced in conversational speech. This ensured that all sentences were heard in both conversational and clear style across listeners. No listener heard the same sentence twice. Sentences were presented through Sennheiser HD570 headphones while the screen display remained blank. Sentences were separated by 1500 ms of silence.

After listening to each block of 12 sentences, participants wrote down their responses in a recall booklet. The participants were asked to recall and write down the rest of the sentence next to the cue on the recall booklet (e.g., "drank the dark coffee" or "baked the delicious cookies"). The three content words to be recalled were counted for keywords recall score. The sentences within each block contained no repetition of written cues or target words. The recall cues were provided in the booklet in the serial order of audio presentation; however, participants were not instructed to fill the recall booklet in any particular order. The recall test was self-paced. Participants pressed a button to initiate the audio presentation of the next block of 12 sentences. The whole experimental session lasted approximately 45 min.

### D. Analysis

The effect of speaking style on recall was assessed in two ways. The percentage of keywords recalled per speaking style (*keyword recall*) provided a quantitative measurement of recall performance and an evaluation of how much of the speech content was recalled verbatim. There were 216 keywords (108 per speaking style) to be recalled. Each recalled keyword was scored as either correct (1) or incorrect (0). We adopted a strict scoring criterion whereby any morphophonological mismatch (e.g., "flowers" instead of "flower") was scored as incorrect. Listeners were not penalized for obvious spelling errors. In the case of uncertainty due to handwriting, the first author consulted the second author and consensus was reached. Binomial logistic regressions were conducted using the generalized linear mixed-effects regressions (GLMER) function of the lme4 package in R (Bates *et al.*, 2015) with keyword recall (0-1) as the dichotomous dependent variable. The model included Speaking Style (Conversational$_{[reference]}$ vs Clear) and Listener Group (Native$_{[reference]}$ vs Non-native) as the independent variables, Speaking Style × Listener Group as an interaction term, Word Position (1, 2, 3) as a covariate to account for the position of the word in the sentence, Block Position (1–6) as a covariate to account for practice effects, and Sentence Position (1–12) as a covariate to account for serial position effects within each block of 12 sentences (i.e., primacy and recency). Subject and Stimuli were modeled using a random intercept term.

The second measure addressed whether sentences were recalled as entire units of connected meaning (*sentence recall*). Responses were categorized as belonging to 1 of 5 categories (with no overlapping membership possible): verbatim, paraphrase, partial, error or omit [adapted from Brewer *et al.* (2005), Sampaio and Konopka (2013), and to some extent Chan *et al.* (2019)]. Scoring was done by the first author and the second author was consulted for ambiguous responses. To ensure consistency across multiple responses, a log with recurring paraphrase, partial or error responses was kept and referred to when scoring new sentences. Table II shows the scoring schema using the target example: "The grandfather drank the dark coffee." Scoring beyond the individual target keywords correct allowed us to distinguish among varied responses where the intended message conveyed by the original sentence was recalled. It also allowed us to differentiate the missing responses from the responses where the recall deviated from the intended message (both scored as incorrect in the keyword recall analysis). A multinomial logistic regression (MLR) was conducted for the categorical dependent variable with multiple unordered recall response categories. MLR captures overall modulation of response probabilities while avoiding the statistical issues raised by non-independent tests such as repeated binary logistic regressions. Using the mlogit package in R (Croissant, 2015), we specified Category membership (Verbatim$_{[reference]}$, Paraphrase, Partial, Error, or Omit) as the dependent variable and Speaking Style (Conversational$_{[reference]}$ vs Clear) and Listener Group (Native$_{[reference]}$ vs Non-native) and their interaction as the independent variables.

## III. RESULTS

### A. Keyword recall

Figure 1 shows the keyword accuracy results for native and non-native listeners in two speaking styles. Results from the logistic regressions on keyword recall showed a

TABLE II. Scoring schema for sentence recall accuracy for the target sentence: "The grandfather (cue) drank the dark coffee."

| Score | Response | Example of response |
|---|---|---|
| Verbatim | Entire sentence with the original wording. | drank the dark coffee |
| Paraphrase | Wording changes that did not alter the gist meaning of the original sentence (e.g., synonym shifts, or additions of implied information). | drank the black coffee |
| Partial | Some lexical information from the original sentence, but the response was deficient, lacking or deviated from the original meaning (e.g., loss of non-redundant information, non-synonymous word shifts, and addition of information not implied by the original sentence). | drank the coffee/drank the cold coffee |
| Error | No information from the original sentence. | built the wooden table |
| Omit | No written response. | |

significant main effect of Speaking Style (*Odds Ratio* [*OR*] = 1.41 [95% *CI*: 1.32–1.50], $p < 0.001$) but no effect of Listener Group (*OR* = 0.8 [95% *CI*: 0.58–1.11], $p = 0.18$). The Speaking Style × Listener Group interaction was not significant (*OR* = 1.13 [95% *CI*: 0.99–1.30], $p = 0.07$) and therefore was removed from the model before interpreting the main effects. We tested an alternative model in which the Talker Group variable was split into three levels ["monolingual" ($n = 33$), "non-monolingual" ($n = 24$) and non-native ($n = 31$) English speakers] and found no significant effect of Talker Group on recall ($p = 0.26$). The parsimonious model with two levels (native vs non-native) was elected as a better model in an analysis of variance model comparison (Baayen *et al.*, 2008) as the alternative model failed to improve the model fit ($\chi^2 = 0.82$, df = 1, $p = 0.37$). We concluded that a significant exposure to another language in addition to English did not differentially affect recall of our listeners in this study.

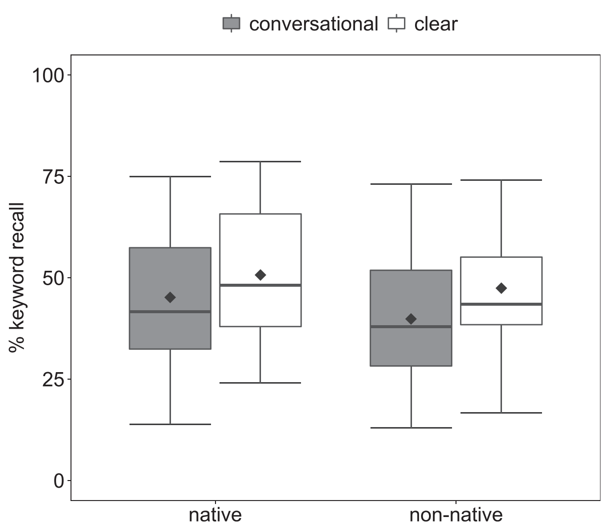


FIG. 1. Percent keyword accurately recalled in conversational (grey) and clear speech (white) and for native and non-native English listeners. Boxplots extend from the 25th to the 75th percentile, with whiskers extending to points within 1.5 times the inter-quartile range. The central horizontal lines indicate the medians and the diamonds indicate the means.

Furthermore, we tested whether recall accuracy could be accounted for by any of the following linguistic variables: age of exposure to English, age of arrival in the U.S., time spent in the U.S., self-rated proficiency in English and L1, current daily exposure to English and L1, number of languages reported before the age of 6, number of languages reported at any age, and type of L1. Model fit was only improved when both self-rated proficiency in English and current daily exposure to English were included the model ($\chi^2 = 7.16$, $p = 0.03$). The main finding, however, remained unchanged (main effect of Speaking Style, $p < 0.001$; no effect of self-rated English proficiency, $p = 0.18$; no effect of current daily exposure to English, $p = 0.23$). The results thus showed that all listeners were able to recall more words from sentences produced in clear speech than in conversational speaking style regardless of their language experience.

## B. Sentence recall

Figure 2 shows the mean and standard error for each response category (in %) for the two speaking styles and the two listener groups. A summary of the direction of the effects of Speaking Style and Listener Group in the MLR is provided in Table III. Results from the MLR showed an effect of Speaking Style on Verbatim, Error, and Omit response rates in the direction expected. That is, the odds of Error responses (*OR* = 0.7 [95% *CI*: 0.59–0.82], $p = 0.002$) and Omit responses (*OR* = 0.74 [95% *CI*: 1.34–1.74], $p < 0.001$) were significantly *decreased* relative to the odds of Verbatim responses in clear speech compared to conversational speech. The odds of Paraphrase ($p = 0.88$) and Partial ($p = 0.08$) responses relative to the odds of Verbatim responses were not significantly affected by Speaking Style. As for the effect of Listener Group, results showed *increased* odds of Omit responses (*OR* = 1.52 [95% *CI*: 1.34–1.74], $p < 0.001$) and Partial responses (*OR* = 1.53 [95% *CI*: 1.31–1.80], $p < 0.001$) and *decreased* odds of Error responses (*OR* = 0.74 [95% *CI*: 0.62–0.90], $p = 0.002$) compared to Verbatim rates for non-native listeners relative to native listeners. The odds of Paraphrase relative to the odds of Verbatim responses were not significantly different for

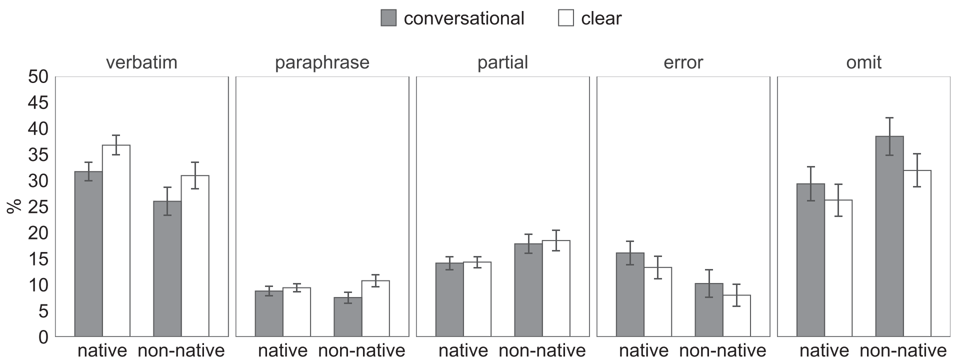


FIG. 2. Proportion of response rate (mean ± SEM) in conversational (grey) and clear (white) speech for native and non-native English listeners.

the two listener groups ($p = 0.056$). No significant interactions were found between Speaking Style and Listener Group.

## IV. DISCUSSION

This study examined native and non-native listeners' recall of sentences produced in conversational and clear speech. We found that clear speech enhanced recall for both listener groups, regardless of linguistic experience. This benefit was evident when both keyword and sentence recall measures were considered. Listeners were able to recall more individual words as well as entire sentences verbatim in clear speech compared to conversational speech. The clear speech benefit was also manifested in lower error rates (where response contained no information from the original sentence) and in fewer omitted responses (where no response were provided at all). These results extend previous findings linking speech clarity to improved sentence recognition memory (Gilbert *et al.*, 2014; Keerstock and Smiljanic, 2018; Van Engen *et al.*, 2012) by providing evidence that clear speech enhances recall, a more complex and effortful form of memory.

The sentence results showed that the clear speech benefit goes beyond the recall of a "list" of words to include deeper linguistic encoding at the level of syntactic and semantic information. This effect may not be attributed solely to enhanced clear speech intelligibility (Keerstock and Smiljanic, 2018; Van Engen *et al.*, 2012) since both clear and conversational sentences in the current study were presented in quiet, at equal intensity levels, and were therefore presumably similarly intelligible. Listening to clearly produced sentences still led to better recall. This suggests that hearing conversational sentences, which are typically produced with reductions and even deletions of some speech segments, may be more effortful and require additional cognitive resources resulting in diminished recall. Conversely, clear speech may have freed up cognitive resources for deeper processing of the speech signal and storage in memory [cf. "effortfulness hypothesis," McCoy *et al.* (2005) and Rabbitt (1968, 1990), and "ease of language understanding" model, Rönnberg *et al.* (2013)]. It is further possible that the hyper-articulated clear speech provides listeners with higher certainty about what is being said so that they are less likely to record an erroneous response or omit a response altogether. Further work is needed to better understand the link between the varied recall responses and speaking style modifications.

TABLE III. Direction of the effects of Speaking Style and Listener Group on sentence recall response category in the MLR. Arrows represent a significant increase or decrease in the odds of a particular response type (error, omit, paraphrase, partial) relative to a Verbatim response (set as the reference level in the MLR) in clear speech compared to conversational speech, and for non-native listeners compared to native listeners. In row 1, the odds of making a Verbatim response was evaluated by changing the reference level to Omit. "*n.s.*" indicate a nonsignificant effect.

| | Effect of clear (relative to conversational) | Effect of non-native (relative to native) |
|---|---|---|
| Verbatim | ↑ | ↑ |
| Error | ↓ | ↓ |
| Omit | ↓ | ↑ |
| Paraphrase | *n.s.* | *n.s.* |
| Partial | *n.s.* | ↑ |

One contributing factor to the memory benefit may be the duration of the clear speech sentences. Clear speech modifications involve a decrease in speaking rate and an increase in pausing. If the total time spent processing is correlated with subsequent memory performance [total-time hypothesis, Cooper and Pantle (1967)], it is possible that longer clear speech sentences provide listeners with more processing time compared to shorter conversational sentences which in turn benefits memory retention. However, the opposite could also hold in that cognitive performance is degraded when processing time is increased as the products of early processing may no longer be available by the time later processing is complete [cf. processing-speed theory, Salthouse (1996)]. More work is needed to assess the contribution of duration and other conversational-to-clear speech modifications on linguistic processing and cognitive functioning.

Similar to the sentence recognition memory findings reported in Keerstock and Smiljanic (2018), the results here showed that non-native listeners were able to use conversational-to-clear speech modifications to significantly improve recall. This was true for both word and sentence recall measures; keyword and verbatim recall were higher while omit and error were lower in clear speech compared to conversational. Closer examination of the whole-sentence recall patterns, however, revealed some differences between the two listener groups. Compared to native listeners, non-native listeners overall recalled fewer entire sentences verbatim, recalled more incomplete (partial) sentences, and were more likely to omit a response than native listeners. These results are in line with findings showing reduced recall in L2 compared to L1 (Hygge *et al.*, 2015; Molesworth *et al.*, 2014; Schweppe *et al.*, 2015). These differences likely reflect a difficulty in L2 processing found at all levels of linguistic structure, from sounds (Best and Tyler, 2007; Flege, 1995) to syntax (Ojima *et al.*, 2005), even for highly proficient L2 speakers (Stepanov *et al.*, 2019). Non-native listeners' higher omission rate and lower error rate compared to native listeners may suggest that non-native listeners were less likely to attempt responding or guessing when unsure. The higher rate of incomplete partial responses for non-native listeners may further highlight their difficulty in making use of top-down knowledge to fill in missing information (Bradlow and Alexander, 2007; Schweppe *et al.*, 2015). Processing highly variable speech and committing information to memory is a difficult and effortful task for any listener, but is particularly challenging for non-native listeners. Despite these difficulties, the lack of an interaction between speaking style and listener group is notable because it shows that the clear speech benefit on recall is significant even among listeners who are not fully proficient in the target language.

This study represents the first examination of the effect of clear speech on native and non-native listeners memory using a cued-recall task. It is well established that speaking clearly enhances word recognition in noise for a variety of listener groups. The results presented here add further evidence that highly intelligible clear speech enhances memory beyond recognition of spoken speech to recall of the message conveyed in the speech signal. The results support the idea that processing clear speech may reduce effort in memorizing spoken information in L1 and L2 processing. This research has implications for daily interactions in challenging environments, such as hospitals or classrooms, where successful information recall may impact health and learning outcomes (Bankoff and Sandberg, 2012; Latorre-Postigo *et al.*, 2017; McGuire, 1996).

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